



## Wind Energy and Atmospheric Physics Department annual report 1998

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# **Annual Report 1998**

## **Wind Energy and Atmospheric Physics**

### **Department**

**P. Hauge Madsen, P. Nørgård and B. Skrumsager (eds)**

**Risø National Laboratory, Roskilde**  
**November 1999**

**Abstract**

The report describes the work of the Wind Energy and Atmospheric Physics Department at Risø National Laboratory in 1998. The research of the department aims to develop new opportunities in the exploitation of wind energy and to map and alleviate atmospheric aspects of environmental problems. The expertise of the department is utilised in commercial activities such as wind turbine testing and certification, training programmes, courses and consultancy services to industry, authorities and Danish and international organisations on wind energy and atmospheric environmental impact.

A summary of the department's activities in 1998 is presented, including lists of publications, lectures, committees and staff members.

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# 1 Introduction

The departments research activities on wind energy and atmospheric processes have the overall objective to advance

- the competitiveness of the Danish wind power industry, setting the scene for implementation of the national energy policy in the area of wind energy and furthering the global application of wind power, and
- the atmospheric physics basis of assessment and forecast of wind effects, transport, conversion and exchange of atmospheric gases and particles in relation to climate studies, air pollution and accidents.

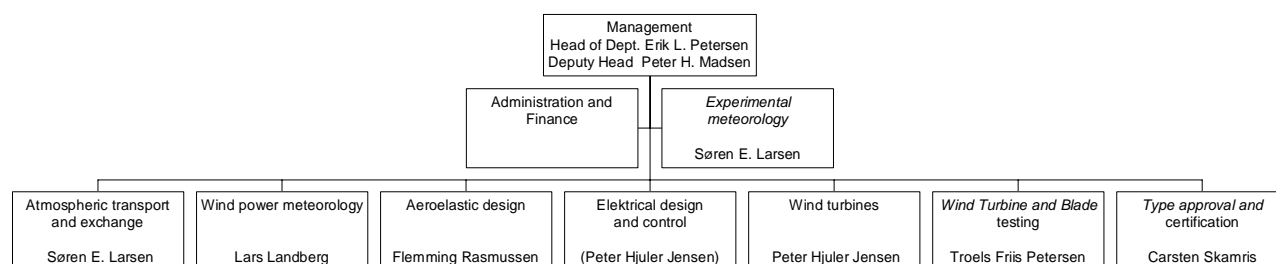
Hence the department aims to meet the need for new knowledge and consultancy assistance on wind turbine technology and the exploitation of wind energy, as well as to map atmospheric processes and alleviate airborne pollution. The research is carried out in co-operation with industry and other users of the research results and in close collaboration and in alliances with national and foreign universities and research organisations.

In 1998 the department engaged 88 man-years, 10 of which involved PhD students and post-doctoral researchers. The research has been organised in five research programs

- Atmospheric Transport and Exchange
- Wind Power Meteorology
- Aero-elastic Design
- Wind Turbines
- Electric Design and Control

In addition the department has performed the commercial and technical support services

- Type Approval and Certification
- Test and Measurements
- Experimental Meteorology



The key areas of scientific expertise in the department are boundary layer meteorology, aerodynamics, aero-acoustics, and machine and construction technology. The fields are advanced exploiting full-scale field tests, laboratory tests and advanced numerical simulation.

The annual report presents the department and the results in 1998, including the programmes and services, research highlights and other achievements. The report also presents lists of publications, lectures, committees and staff members.

Additional information on the department and its activities can be found on World Wide Web (WWW) on the address <http://www.risoe.dk/amv/>. The departments web pages are constantly updated.

## **2 Wind Energy and Atmospheric Physics Department 1998**

The department has experienced satisfactory progress also in 1998. All of the department's research programmes and special tasks have shown important results. A few noteworthy key research results to be mentioned are as follows. The research programme Atmospheric Transport and Exchange has developed a new parameterisation of stable boundary-layer conditions of special importance for numerical modelling. The research programme Wind Power Meteorology has finalised a project on short-term prediction of wind energy production in co-operation with EPRI and Danish utilities. The programme Aeroelastic Design has further developed the numerical wind tunnel and performed CFD-calculations (Navier-Stoke solution) for a full wind turbine rotor and numerically determined 3D airfoil data. The programme Wind Turbines has initiated a research programme on off-shore wind farms in co-operation with the Danish utilities and the programme Electrical Design and Control has concluded a survey of grid quality issues for wind farms on weak grids in India. Key results from the department's special tasks servicing the wind turbine industry are the development, accreditation and intensive use of the blade test facility in Sparkær and the accreditation to carry out Dutch type approvals of wind turbines.

The work in the department has been performed in a close co-operation with the Danish wind turbine industry, the Danish Energy Agency, the Ministry of Environment and Energy, the National Environmental Research Institute, Danish Meteorological Institute, Danish Technological Institute and Norske Veritas. The work has involved also a range of Danish and foreign universities and research institutes. EU research programmes and programmes under the Danish Ministry of Environment and Energy have sponsored a large part of the department's research activities.

The department maintains its profile in international research and development co-operation. In addition to our participation in international research programmes, the department plays an important role within various organisations. Among these are IEC (International Electrotechnical Commission, the international standardisation organisation for wind energy among other topics),

CENELEC (the European standardisation organisation), EUREC-Agency (the European co-operation organisation for renewable energy research institutes), IEA (the international energy agency) and EWEA (the European Wind Energy Association). A high profile but also very time-consuming task in 1998 has been the planning and co-ordination of the next European wind-energy conference, scheduled for March 1999. The conference chairman as well as the programme chairman is from the department.

The main results of the department in 1998 are illustrated below.

Risø's research into wind energy and atmospheric processes aims to advance the international competitiveness of Danish wind turbine industry, setting the scene to implement a Danish energy policy in the area of wind energy and furthering the global application of wind power. The program also covers research into the atmospheric physics basis of assessing and forecasting wind effects, transport, conversion and exchange of air pollution and other airborne particles, together with the consequences of accidents.

### **Wind atlas for Egypt**

Work began during 1998 on a wind atlas for Egypt. The project is one of the largest wind resource studies ever, making use of advanced wind flow modelling as well as meteorological and satellite data. It is sponsored jointly by the Danish and Egyptian governments and is being carried out in conjunction with the Egyptian meteorological institute and the New and Renewable Energy Authority (NREA) in Cairo. The contract was negotiated with Danida.

### **Extreme winds in Denmark**

In the EFP WAsP engineering project, a numerical tool is being developed in consultation with a Danish consultant to calculate extreme winds and turbulence to determine the load basis for wind turbines for arbitrary siting in Denmark using the WAsP method. Among other aspects, the analysis supports the reduction of extreme winds over large parts of Denmark put forward in the new Danish standard on wind load.

### **Wind turbine loads and safety**

A numerical tool for probability analysis of loads and stresses in wind turbine components has been developed in collaboration with colleagues in Denmark and abroad. It can be used in standardisation work and as an instrument for the industry and the approval system.

### **Improved calculation tool for the wind turbine industry**

Aeroelasticity describes the relationship between the structure of a wind turbine and the flexibility of the structures as well as the flows around the wind turbine. This is a key point in wind-turbine design. The results of this research are implemented within the HawC aeroelastic program, developed by Risø. The program is used e.g. in the wind turbine industry to determine loads and optimum dynamic characteristics in the development of new MW-size wind turbines. As discussed in the introduction, the program has been used in the design of the Bonus 2 MW wind turbine.

### **Numerical wind tunnel**

Wind turbine manufacturers can save costly development time by carrying out profile tests in Risø's virtual wind tunnel - the numerical wind tunnel - instead of a "real" wind tunnel. Risø and DTU have developed the Navier-Stokes EllipSys2D/3D calculation program, which is well suited to perform calculations



in the numerical wind tunnel. One of the more promising results in 1998 is a new method of extracting blade profile data, intended for use in the so-called BEM method, a standard aerodynamic calculation tool in the Danish wind turbine industry.

### **Calculation and design of blade profiles**

In 1998, for the first time, a set of reliable 3D blade profile data was calculated for a complete rotor in the numerical wind tunnel. The problem of double stalling (the fact that a wind turbine can stall in two different ways in relation to the same wind flow) has a number of negative effects on stall-regulated wind turbines. CFD calculations have now demonstrated that the leading edge of the blade profile can be modified to minimise the problem. A new blade profile design tool has been developed in the EFP "blade design" project; this has been used in the design of a new range of blade profiles giving inter alia improved stalling characteristics, greater aerodynamic conversion efficiency and elimination of the double-stalling tendency.

### **Tests of large blades**

Risø's largest investment in facilities for servicing the wind turbine industry is the blade testing facility at Sparkær, Jutland. Testing in 1998 included tests on the new MW-size wind turbines as part of the development and certification processes. In 1998, Risø was accredited by DANAK to carry out static and dynamic blade tests in Sparkær.

### **Additional accreditation**

In 1998 the accreditation by DANAK was extended to include power curve measurements, measurements of structural loads on wind turbines and static and fatigue testing of wind turbine blades. Testing was performed on wind turbines in the range 0.5-1.5 MW situated in Denmark, Germany and California. Accreditation has also been achieved to conduct Dutch wind turbine type-approvals.

### **Det Norske Veritas, DNV**

The fruitful collaboration on Danish and international approval of wind turbines between Risø and DNV has continued and plans for expansion are underway.

### **Forecast of wind power for Danish utility companies**

A project on short-term forecasting of the production of wind energy in collaboration with EPRI and Danish utility companies has been concluded. The system is now running online with two updates per day. Participating organisations can access it via the Internet.

### **Wind turbines in weak power grids**

The problems of wind turbine parks in weak power grids in India have been mapped in collaboration with DEFU and an Indian research institution and with support from EFP. The project is expected to lead to recommendations for optimised electrical design and regulation, which could also enhance the opportunity for Danish industry to supply integrated solutions.

### **Vestas and ABB**

In co-operation with Vestas and ABB, a first generation combined variable speed and pitch controlled wind turbine has been developed, with significantly reduced loads in the transmission system as a result. Subjects for further investigation and optimisation have been identified, such as an aerodynamic design adapted for variable speed operation and further optimisation of the regulation.

**New concept in wind turbines**

A new flexible wind turbine concept has been developed with support from EFP (the Danish Energy Research Programme) and EU-Joule in co-operation between research institutes and a blade manufacturer. The concept is characterised by a free yawing down wind turbine with nacelle tilting flexibility and a two-bladed teetering rotor with three-point supported blades and built-in structural couplings. Active stall and active coning control power and loads.

**The atmosphere on Mars**

During the 1997 NASA Pathfinder mission, readings were taken of the atmospheric boundary layer on Mars. In 1998 Risø participated in the international group responsible for the analysis and interpretation of these measurements.

**Atmospheric fluxes over land and sea**

Exchange between the atmosphere and land and sea surfaces of air-borne pollution, nutrients and greenhouse gases, as well as heat and water vapour, have been studied with particular regard to climate research in a broad-based Nordic - European joint venture. The absorption of carbon by forests is being investigated in the EUROFLUX project, for which Danish researchers are taking readings in a beech forest near Sorø.

**New testing facility in preparation**

Work continues to establish Risø's new testing facility for large wind turbines in north-western Denmark. Testing activities are expected to be ready to commence in late 1999, subject to approvals of applications pending with the relevant authorities.

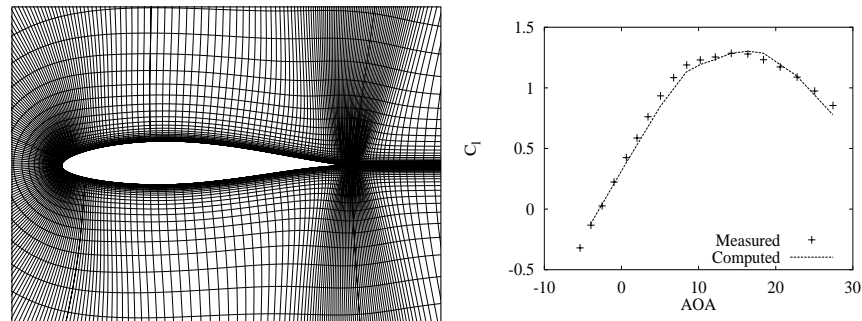
**Development of competence through broad research collaboration**

The programme works closely with Danish wind turbine industry, the Danish Energy Council, the Ministry of Energy and the Environment, NERI (National Environmental Research Institute); DMI (Danish Meteorological Institute); DTI (Danish Technological Institute); DNV (Det Norske Veritas) and a number of Danish and foreign universities and research institutions. EU research programs as well as programs organised under the auspices of the Ministry for Energy and the Environment have sponsored a large proportion of research activities. In addition, agencies such as IEC, CENELEC, EUREC-Agency, IEA and EWEA are represented as participants.

## 3 Selected Activities

### 3.1 Numerical wind tunnel

The ‘virtual or numerical wind tunnel’ is a collection of numerical tools related to aerodynamics and aeroelasticity, which forms an attractive complement to measurements of the aerodynamic behaviour and properties in physical wind tunnels or even full-scale measurements under natural conditions. The method become more and more reliable, and when the know-how and the toolbox are first established, the use of the numerical tools provide a much less expensive and faster option, than doing an experiment, allowing evaluation of different designs before validating of the final design by measurements.



*Figures 1 and 2. Typical C-mesh used for airfoil computation, holding 384x64 cells and comparison of computed  $C_\alpha$  curve for the Risø profile at  $Re = 1.6 \times 10^6$  with measurements.*

A fundamental part of the numerical wind tunnel is the general purpose Navier-Stokes solver, the EllipSys code. The EllipSys is developed and implemented in co-operation between The Department of Energy Engineering at DTU and the Wind Energy and Atmospheric Physics Department at Risø. As the calculations are rather computer time consuming, the code has been paralleled for execution on distributed memory machines, making it possible to run on modern large scale computer facilities, as the 64 processor IBM SP2 parallel computer at the Danish Computing Centre for Research and Education, UNIC.

#### **Airfoil computations**

Steady and transient two-dimensional airfoil flows are areas, where the EllipSys program is intensively used. The EllipSys tool has been utilised in the design of airfoils to verify new designs before measuring in the wind tunnel. The capability of the numerical code to compute laminar to turbulent transition is extremely important for these applications, as the exact location of the transition point is essential for predicting the correct airfoil characteristics.

In connection with unsteady airfoil characteristics, the code is being used to compute dynamic stall flows. This type of computations is valuable when evaluating the aerodynamic damping properties of an airfoil section. In contrast to measurements, often limited to pitch oscillations, it is straightforward in the

computations to perform all kinds of oscillations - pitch, plunge, lead-lag and combinations of these.

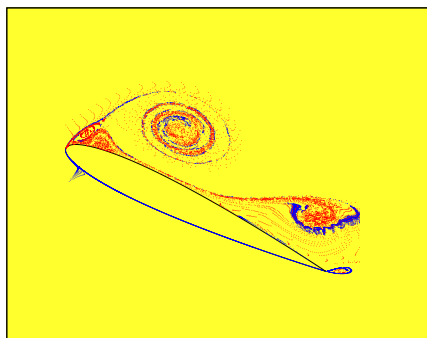
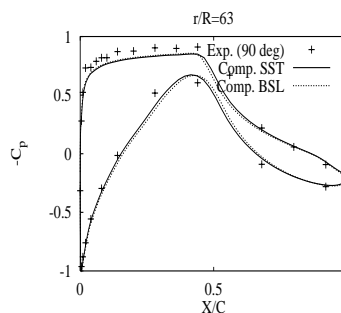
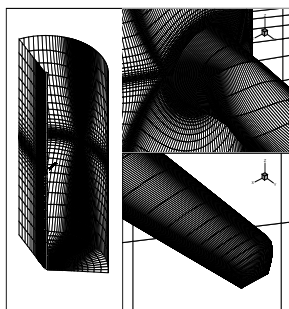


Figure 3. Dynamic stall vortex on a NACA 0015 airfoil

As an extension of the analysis of the dynamical behaviour of airfoils, the EllipSys program has recently been coupled to a simple three degrees of freedom elastic model. This allows direct computations of the aeroelastic behaviour of airfoil sections.

### Rotor computations

Computations of the flow around wind turbine rotors have for the last years been investigated in the numerical wind tunnel. The computations provide detailed information about the flow, e.g. pressure distributions, skin friction distributions and limiting streamlines on the surface, which usually are not available from full-scale measurements on wind turbines.

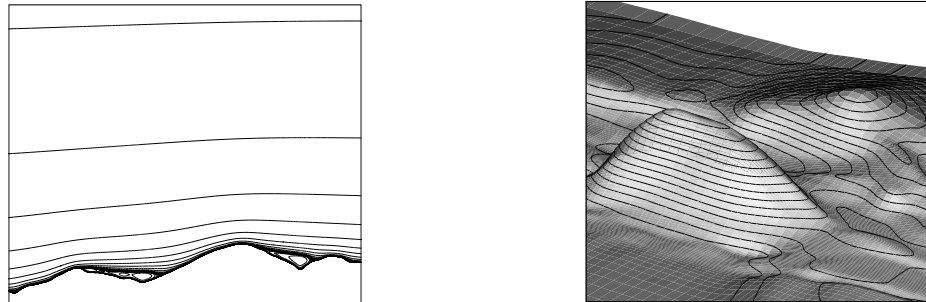


Figures 4 and 5. Mesh for a rotor computation showing a total view of the mesh and details near the root and tip, and predicted and experimental pressure distributions at the  $r/R=0.63$  for the NREL Phase-II rotor at 7 m/s wind speed respectively.

### Natural terrain computations

Complex terrain computation is another area, where the EllipSys code is applied. Even though EllipSys code is several orders of magnitude slower than the WAsP code, the EllipSys is still of great interest due to its ability to predict separated flow. Until now the focus has primarily been on two-dimensional applications, but recently there has been a growing interest in full three-dimensional computations. Typically the output of this type of computations are

streamline patterns, speed-up factor along selected lines, and profiles of turbulence intensity. Additional information about the local wind direction both in horizontal and vertical direction is useful when operating wind turbines in complex terrain.



*Figures 6 and 7. Stream lines showing large re-circulating regions on the lee side of two hills, and typical terrain representation used in the EllipSys3D model, respectively.*

### 3.2 Wind turbine and blade testing

Measurements on wind turbines take place in order to validate the energy production and safety levels. Measurements are therefore vital to the whole wind energy community, especially manufacturers, developers, certification authorities and financial and investment institutes.

The test and measurement group at The Test Station for Wind Turbines at Risø has a world leading experience in measurements on wind turbines and in blade and component testing. More than twenty years of experience in wind turbine testing on more than 60 types of wind turbines form the basis of the test programs carried out by the Test and Measurement Group.

The Test Station for Wind Turbines was established in 1978. The test and measurement group was formed back at this early stage. Today it is a section of the Department for Wind Energy and Atmospheric Physics at Risø National Laboratory. In 1995 the test and measurement group was accredited to perform measurement on wind turbines according to the European Standard EN 45001.

The group has its domiciles at Risø and at Sparkær in Jutland. A coming test location in north-western Jutland is expected to be the main test facility for wind turbines in the next millennium. This location has all the best conditions for wind turbine testing, and is one of the windiest places in Denmark. The location holds up to 5 MW size wind turbines.

Risø has six standard foundations, and wind turbines up to 600kW can be tested. Until the beginning of the nineties all measurement activities were mainly carried out at Risø. Most of the Danish prototype wind turbines were tested at Risø at that time. As the wind turbines increased in size, field-testing became common. Today the test and measurement group performs full-scale tests on wind turbines world-wide. The measurement results are transferred to

Risø via modems, satellite or through the Internet. Selected wind statistics from several measurement campaigns can be followed online on the Internet.



*Figure 8. Risø Sparkær Blade Testing Centre*

The first blade test facilities at Risø became gradually too small for the fast growing wind turbine blades. Therefore in 1992 Risø made a major step forward, by taking over the Sparkær Centre blade test facility. The Sparkær Centre had on a private basis carried out blade tests since 1984. In 1997 the test facilities were extended. Risø is now deeply involved in static and dynamic tests on the new generation of large wind turbine blades.

Risø has a long tradition in development of instruments for atmospheric boundary layer field experiments and wind turbines testing. The instrument development group is supporting the test and measurement group in their efforts to improve the accuracy and response of instruments in order to better the quality of the measurements.

Risø offer the following wind turbine tests:

- power curve measurements
- structural loads
- test of the safety system
- noise measurements
- grid interfacing
- yaw efficiency
- dynamic response at stand still
- dynamic response during operation
- system tests
- basic tests

Risø offer the following blade tests:

- static blade tests
- fatigue blade tests
- component tests (hub, nacelle etc.)
- damping & frequency measurements

The test and measurement group is a member of MEASNET, which is an international co-operation between companies, which perform commercial accredited testing of wind turbines. The organisation has the objective to ensure and improve the quality of measurements by a quality and evaluation program.

In addition to the commercial activities the test and measurement group is engaged in standardisation of measurement procedures. Membership of several committees under the IEC and CENELEC standardisation organisations supports the wind energy community with relevant and highly developed procedures.

Risø participate in research projects within the European program on Standards, Measurement & Testing (SMT) which has objective of the SMT to support standardisation work in CENELEC and IEC. Risø also participate in research projects under the European JOULE-program to support more fundamental research within the wind energy field

The Danish Energy Council is the main sponsor of our non-commercial activities and provides, together with Risø, the basic funds for our participation in research and development projects. These activities and conditions ensure that we, also in the future, will put the highest emphasis on performing high quality measurements on wind turbines.

### **Power curve measurements**

Power performance is one of the most important characteristics of a wind turbine on which the whole economy of a wind energy project depends. Power curve measurements relate to the power output from the wind turbine to the wind speed. This enables calculation of the annual energy production under different wind climates. Power curve measurements are therefore vital for the wind energy community.

For a power curve measurement a minimum of eight parameters are recorded. A meteorology mast must be erected at a distance to the turbine of approximately 2.5 times of the rotor diameter. The wind speed is measured on the meteorology mast at hub height. The test and measurement group uses rapid sampling computers for measurements. This ensures that peaks are recorded accurately. Furthermore the measurement system is very flexible and can be expanded to measure a variety of parameters for a whole system test.

The group has performed power curve measurements since 1976. Since then, countless power curve measurements have been performed. In 1995 the test and measurement group was accredited for power curve measurements according to the European standard EN 45001 "General criteria for the operation of testing laboratories". Accreditation of new power performance procedures has been obtained as soon as they have been developed and issued.

The test and measurement group is a member of the international MEASNET organisation. The work implies regular round robin tests of reference anemometers and inter-comparison of power performance measurements. The group has taken part in an IAE round robin test, where the same wind turbine was sent around the world to participants (Test Stations) for power curve measurements. The power curve measured at Risø will be compared to results from the other participants.

The test and measurement group has performed power curve measurements in many countries throughout the world. Online connection to Risø enables data to be transmitted from the measurement system at any time.

The group performs accredited power curve measurements according to the following power performance standards:

- Danish
- Dutch
- IEC (International)

- MEASNET

### **Mechanical load measurements**

Mechanical load measurements on wind turbines take place in order to validate load calculations related to wind turbine certification or direct determination of the loads under specific conditions. The best way to determine structural safety limits is mechanical load measurements. They are therefore vital to the wind energy community: manufacturers, developers, certification authorities and the financial sector.

Strain gauge installation is a service offered to the industry on a regular basis, both in Denmark and abroad. The technicians and engineers of the test and measurement group attend courses in strain gauge installation and instrumentation techniques in order to update their knowledge of the current developments. The group has more than twenty years of experience in mechanical load measurements. Substantial know-how in the area of strain gauge installations has been built up and this allows instrumentation under different and many times not favourable conditions with good results.

The group performs mechanical load measurements in and outside Denmark. In order to service different customers with different needs, the group possesses a variety of instrumentation which can be used after a qualified judgement of the specific project needs. Since load measurements, as a rule, take place during the development of a wind turbine, the concept behind these measurements is interaction with the customer and fast data delivery. As a result, on-line data transfer to our premises is always a part of a measurement. Along with that, data analysis takes place automatically as the necessary software is developed in advance. This is a cost-effective solution for the test and measurement group and our customers.

The concept behind all our measurement systems is flexibility. The test and measurement group can meet the needs of its customers whatever the amount of channels that need to be measured, either in the fast or rotating part of the wind turbine. Both our hardware and software are designed to meet these demands and for this reason the test and measurement group has chosen to perform these measurements combining measurement computers and data loggers.

Having performed several mechanical load measurements, the test and measurement group was in 1998 accredited to perform these measurements according to the European standard EN 45001 "General criteria for the operation of testing laboratories". This accreditation is yet another proof of the high standards that the group attains in its work.

The test and measurement group performs accredited mechanical load measurements of the following wind turbine parameters:

- Yaw efficiency during operation
- natural frequencies at stand still
- structural loads

These services are offered to customers within the wind energy community: the private as well as the public sector. The measurement projects cover both commercial and public research and development (basic and applied) activities.



They cover the following fields:

- Installation of sensors (strain gauge sensors, accelerometers).
- Instrumentation with the corresponding measuring equipment (eg bridges, telemetry equipment or similar, data acquisition and data transfer).
- data analysis and on-line calculation of fatigue loads.

The test and measurement group actively participates in the development of international standards for the measurement of mechanical loads (IEC/TC88, MEASNET). Moreover the group is a member of the international MEASNET organisation which is a co-operation between testing companies performing commercial accredited testing of wind turbines.

### **Blade testing**

One of the most critical parts of a wind turbine is the rotor blade. Failure of a rotor blade in service often involves damage of the entire turbine. The economical consequences of a rotor failure can be devastating to a wind turbine project wherever situated on the globe. Although most blade designs and calculations are now performed on computers, there is a strong need to verify these calculations by full-scale blade tests. Full-scale static and fatigue tests normally cost relatively little compared to the price of one single rotor blade.

Since 1981 Risø has tested rotor blades. The original blade test facilities at Risø became gradually too small for the fast growing wind turbine blades. Therefore, in 1991 Risø made a major step forward, by taking over the Sparkær Centre blade test facility, which on private basis has carried out blade tests since 1984.

In 1997 the test facilities at Sparkær were extended with a new test hall with test rigs allowing tests of rotor blades up to 45 meter in length.

In 1998 the Sparkær Centre was accredited according to the European standard EN 45001 "General criteria for the operation of testing laboratories". The accredited measurements are:

- static blade tests
- fatigue blade tests
- determination of natural frequencies

The test and measurement group participates in research projects within the European program on Standards, Measurements and Testing (SMT) making a database of blade test data.

Most of our activities are financed by commercial tests for European blade manufacturers. The Danish Energy Council is a main sponsor of our non-commercial activities and provides together with Risø the basic funds for our participation in research and development projects. Development projects are all performed in close co-operation with colleagues at other departments of Risø. These activities and conditions ensure that we, also in the future, will put the highest emphasis on performing high quality measurements on wind turbine blades and components.

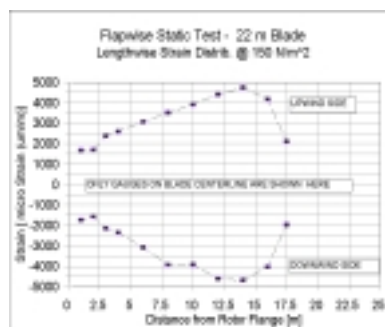
### **Static blade test**

Static blade tests are performed in order to determine the structural properties of a blade including natural frequencies, stiffness data and strain distribution. The

reported data enable certifying bodies to compare measured data to the calculated data of the design criteria. Thus full-scale blade tests are an essential part of the approval process. Design engineers in the process of enhancing structural design concepts also use test results.



*Figure 9. Flap-wise static test of a wind turbine blade at Risø Sparkær Centre.*



*Figure 10. Surface strain distribution along the blade during static test of the blade in the test bench.*

Accredited static load tests performed at the Sparkær Centre consist of the following standard parts.

- determination of physical properties
- determination of natural frequencies
- flapwise proof test
- edgewise proof test

A typical blade test includes the following. After receipt of the blade, the blade length, mass, own weight moment and centre of gravity are determined. Strain gauges in a number of 60 – 120 are applied to the blade skin and internal blade structure. The blade is bolted to the test rig. Structural damping and natural frequencies are measured. The slope of the strain graph is essential information for the verification of the structural blade design. The length-wise presentation of the strain distribution can reveal high strain gradients that could reduce the fatigue life of the blade.

Failure of megawatt size turbine blades can represent a significant safety risk to engineers and technicians involved in the test. Therefore a specially designed impact resistant mobile shelter has been developed and manufactured.

All personnel and data acquisition equipment is situated here throughout the test loading and measurement equipment are remotely controlled.

In addition to the standard tests described above, the Sparkær Centre has also performed static tests of wind turbine hubs, turbine nacelles and fatigue tests of blade roots.

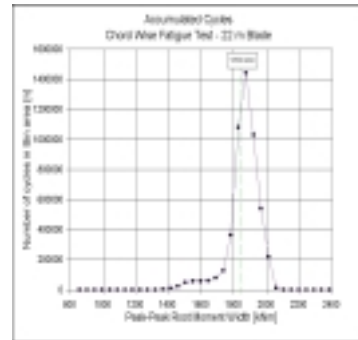
### **Fatigue blade test**

Fatigue blade tests are performed in order to determine the fatigue properties of a blade. The reported data enable certifying bodies to compare measured data to the calculated data of the design criteria. Thus full-scale blade fatigue tests are often an essential part of the approval process. Design engineers in the process

of verifying enhanced structural design concepts also use test results. Blade failures observed in the field can also be duplicated at a fatigue test.



*Figure 11. Chord-wise fatigue test of a wind turbine blade at Risø Sparkær Centre.*



*Figure 12. Example of the number of cycles and blade root moment in an accelerated chord-wise fatigue test.*

Accredited fatigue tests performed at the Sparkær Centre normally consist of the following standard parts:

- edgewise fatigue test of 5 million cycles
- flap-wise fatigue test of 5 million cycles
- final static proof test
- thermal image inspection

A typical fatigue blade test includes the following. The blade is bolted to the test rig with vertical tip chord. A static test is performed to obtain strain- and stiffness information for the blade. For each test direction 30 strain gauges measure strain in the blade skin or blade internal structure. The edgewise test of 5 million cycles is then performed. A frequency converter, controlled by a computer, powers the electric motor exciter, mounted on the blade. The blade oscillates at a frequency close to its natural frequency. The control system ensures that the peak-peak root bending moment of the test is kept constant. In some chord-wise tests a flap-wise constant load is applied to the blade, simulating an average wind load.

The load spectrum of the test is obtained from information stored in bins on the computer hard disk. For each cycle, the root bending moment width (peak-peak) is determined and stored, to give the moment width spectrum. For each 10.000 cycles a scan of all strain gauges are performed automatically, to give the strain width at every gauge position. At regular intervals of 1 million cycles a static test is performed.

After the chord-wise test, the blade is turned, to have the tip chord in a horizontal position for the flap-wise test. The main exciter is mounted at approximately 75 % blade length. A mass pre-load is mounted on the main exciter to give the desired average root bending moment. A dead load exciter is placed near the tip to give the correct bending moment distribution. The blade is now subject to five million cycles at a constant root bending moment width.

As the blade interior is accessible through the blade root, design engineers can study movements of the internal blade structure during the fatigue test. Follow-

ing the fatigue test, a final proof test is performed to verify that the remaining strength of the blade is sufficient for safe operation of the blade.

### **Thermal imaging**

For low cycle fatigue tests and standard fatigue tests the use of thermal imaging has now been developed and adopted as a standard procedure at all fatigue tests. The technique is used to spot possible problem areas on the blade. This is a great help to blade designers. Thermal hot spots show energy dissipation deriving from internal friction in the blade matrix. This happens in areas where the structural damping works, or where the blade material disintegrates. Structural damping of an oscillation converts the mechanical energy of the oscillation into heat energy in the composite material. Thus the thermal hot spots tells about "structural damping at work" or of severe fatigue damage areas.

In addition to the standard tests described above, the Sparkær Centre has performed also static tests of wind turbine hubs, turbine nacelles and fatigue tests of blade roots.

## **3.3 MET-RODOS a network-integrated real-time atmospheric dispersion system**

MET-RODOS is a network-integrated comprehensive meteorological dispersion forecast module for emergency response. Presently it is being implemented in the harmonised European real-time decision support system for nuclear emergencies called RODOS, and in the Danish emergency response modelling system called ARGOS-NT. The real time dispersion system also finds applications within animal disease control from airborne spread.

MET-RODOS is designed to provide forecasts of dispersion, gamma doses and deposition from multi-nuclide releases on local, national and continental scales. The computerised module enables real-time forecasts via a nested set of local and long-range wind and atmospheric dispersion models that in turn are driven by on-line available meteorological information. Meteorological information is made available to the system via on-line connections to local meteorological observations (met-towers and sodars) and via on-line network connections to Meteorological Services. The system provides pt European scale forecast of up to +48 hours by use of Numerical Weather Prediction data downloaded from the Danish DMI-HIRLAM weather forecast model.

The system is being implemented as part of the RODOS system in several Western and Central European Institutes in charge of National or regional emergency response concerning nuclear accidents.

We will mention some of the many meteorological features, the functionality and modelling methods embedded within MET-RODOS. This includes on the atmospheric pre-processors, the local scale wind and turbulence models, the local scale atmospheric dispersion module (a similarity-theory based Lagrangian puff model) - and the long-range (Eulerian) approach applied to the regional (European) scale.

References and links are given to experimental evaluations and inter-comparison studies carried out to evaluate the various modules.

## Introduction

MET-RODOS Atmospheric dispersion system have been designed to provide the EU-RODOS decision support system with real-time dispersion prediction of airborne radioactive spread and deposition on local, national, and European scale. The system runs with measured or estimated source terms and runs on meteorological data provided on-line either from local meteorological tower or via network connections (Internet/ISDN) to operational national or international Numerical Weather Predicting (NWP) centres. The MET-RODOS system is designed to produce actual and forecast ground-level air concentrations and gamma dose rates, and wet and dry deposition estimates.

MET-RODOS is a comprehensive atmospheric dispersion modelling system, established by integrating a number of existing pre-processors, wind, turbulence, and dispersion models together with on-line accessible meteorology.

The dispersion system consists of nested meteorological model chains that combines local and long-range atmospheric dispersion. MET-RODOS is designed to produce estimates of actual and forecasted (+36 hour) ground-level air concentrations, wet and dry deposition and ground-level gamma dose rates on all scales. Furthermore it is designed to accommodate on-line available radiological monitoring data and to assist with source term determination by use of various data assimilation and back-fitting procedures

MET-RODOS comprises a local scale pre-processor (lsp), a local scale model chain (lcmc) and a long-range model chain (lrnc). During run time it accesses on-line met-tower data and real-time numerical weather forecast data in the RODOS real time database.

Concentration, deposition and dose rate estimates are produced by nesting the local and the long-range atmospheric dispersion model chains and by consistent use of the real-time meteorological information available on-line to the system

The MET-RODOS system is equipped with pre-processors, diagnostic wind and puff type diffusion models selected especially for real-time applications within the RODOS framework, cf.: table 1.

Models integrated in the MET-RODOS system, near-range flow and dispersion models, including pre-processors:

- meteorological pre-processor (pad)
- mass consistent flow model (mcf)
- linearised flow model (lincom)
- Puff model with gamma dose module (rimpuff)
- Near-range segmented plume model (atstep)

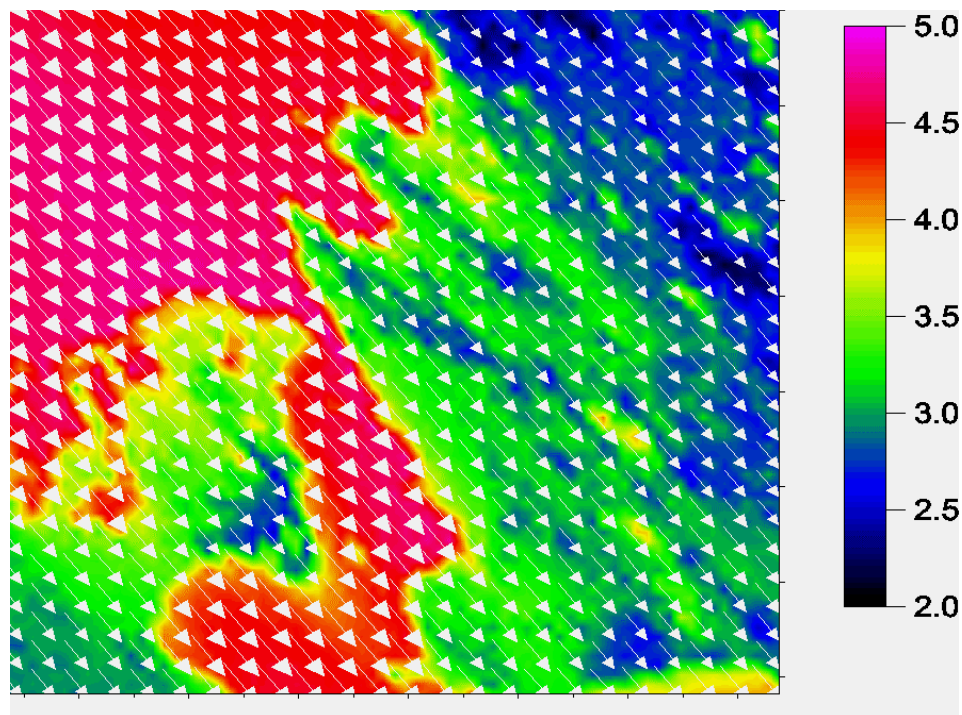
Mesoscale and long-range models:

- Eulerian K-model (match) nested with puff radiation dose models (rimpuff)

On-line weather forecast data:

- numerical weather prediction models (dmi-hirlam and spa -typhoon)

Table 1:



The meteorological pre-processor maintains RODOS real-time data base with actual and forecast local scale wind fields and corresponding micro-meteorological scaling parameters by use of pre-processor and local scale wind models. The local scale model chain contains a suite of local scale wind and dispersion models, such as Lincom and Rimpuff, from which case-specific models are selected depending on the actual topography and atmospheric stability features in question. It provides local scale deposition rates, air concentrations and cloud gamma dose rates in the local scale (about 20-30 km), and it passes on the diffusion specific parameters, such as cloud size and cloud position to the long range model chain. The long-range model chain provides consistent trajectory and dose rate predictions on national and European scales based on access to numerical weather prediction data down loaded and stored in the real-time database.

#### **On-line meteorological data**

A distributed real-time atmospheric dispersion based nuclear emergency system, such as MET-RODOS, requires continuous on-line access to both actual (real-time) measurements of the local meteorology and to numerical weather prediction data. At most nuclear sites in Europe, local-scale meteorology is on-line accessible from meteorological towers or stations located in the vicinity of the release point. The instrumentation of most met-towers comprises wind (cup and wind vanes) and temperature sensors. As released radioactive material eventually is transported to distances beyond the local scale, also estimates of the regional (100 km) scale wind and temperature conditions are requested. Such on-line regional scale meteorology is in some European countries (Hungary for instance) available from a network of on-line meteorological towers.

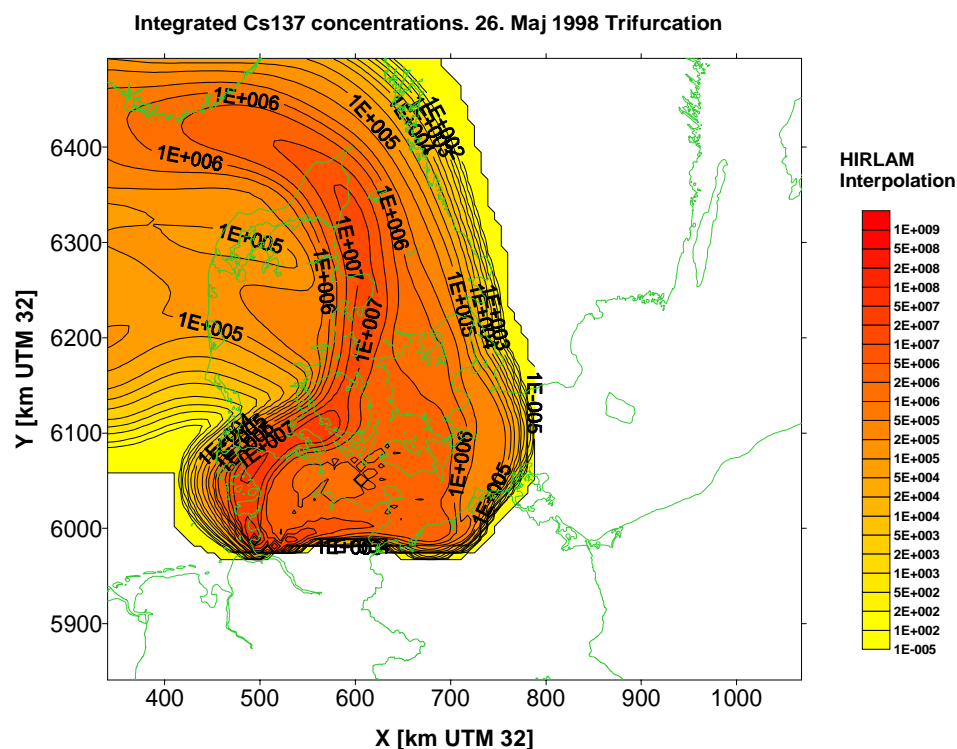
For European scale calculations, quantitative estimates of the actual and forecast (+36 Hr or + 48 hours) wind and temperature conditions is available on-line from numerical weather prediction (nwp) centres in the form of high-resolution

limited area data distributed via computer networks all over Europe. Such data are referred to as numerical weather prediction forecasts, and are usually provided on a commercial basis from operational meteorological institutes in Europe.

### Evaluation through the web-based real-time RTMOD exercises

The MET-RODOS model chain is involved in a web-based real-time model evaluation exercise and study called RTMOD. Risø participates in this exercise

Table 2:



with the Lincom and Rimpuff models from the MET-RODOS module (similarity mode) based on forecast data provided by the DMI-HIRLAM model. The long-range model used is the Swedish Eulerian long-range dispersion model Match]. Further information can be found on the RTMOD home page at <http://rtmod.ei.jrc.it/rtmod/>

### Rimpuff in the service as a prediction tool for airborne spread of pathogenic virus among animals

The computer-based information technology behind MET-RODOS can also assist and support today's animal disease control and animal health assessment. Today atmospheric dispersion models for airborne spread combined with epidemiological models for animal disease spread and outbreaks is at hand for the veterinarian society on simple-to-use and inexpensive desk top computers (PC's).

In connection with EU-Epiman foot-and-mouth disease control system, the modules within the MET-RODOS system have already been set up to integrate geographical information systems (GIS). They contain information on animal population, location, maps for road access etc, and can hold or link to integrated



data bases for farmhouse animal inventory etc. Here the atmospheric dispersion model RIMPUFF developed and maintained by Risø National Laboratory was used in connection with simulation of airborne spread of pathogenic diseases among live stock animals.

The dispersion model RIMPUFF has already been integrated in animal disease control systems such as Danish Slaughterhouses (Danske Slagterier - DS). The Aujeszky on-line early warning system in alert on the island of Als, Denmark is one example. RIMPUFF has also been integrated as the atmospheric module in a joint European/New Zealand decision support system called EU-Epiman for foot-and-mouth disease (FMD) decision support during outbreaks.

To a large extent, virus and bacteria spread in the atmosphere in a similar manner to spread of nuclear aerosols, virus decay, they deposit etc. in similar manners. The description of the Met-RODOS system with RIMPUFF also in many ways applicable to airborne pathogenic virus spread among livestock. With proper assessments of the model source terms, the model can assist estimating, for instance, the daily disease load of virus from neighbouring farms, and can assist also in the prediction of inter-spreading among adjacent farms.

## 4 Research Results

The activities of the department fall within the Risø program area *Wind Energy and Atmospheric Processes*. It has the objective to develop methods for design, test and siting of wind turbines, prediction of wind loads and wind resources as well as methods to determine the dispersion, transformation and effect of air pollution. The department is organised in programs and special services according to its main research and technical activities.

Research programs:

- [\*Atmospheric Transport and Exchange\*](#)
- [\*Wind Power Meteorology\*](#)
- [\*Aeroelastic Design\*](#)
- [\*Electrical Design and Control\*](#)
- [\*Wind Turbines\*](#)

Special services:

- [\*Wind Turbine and Blade Testing\*](#)
- [\*Type-Approvals and Certification\*](#)
- [\*Experimental Meteorology\*](#)

In the "Atmospheric Transport & Exchange Programme" basic research into boundary-layer meteorology and atmospheric turbulence is carried out. In addition we study environmental problems related to transport of air-borne pollutants and turbulent exchange of matter in the interaction between the atmosphere and terrestrial or sea surfaces.

The "Wind Power Meteorology" programme is aimed at assessments of wind resources for power production and wind loads on wind turbines and other constructions. The programme comprises development of models and software, field measurements and in-house as well as commissioned assessment studies.



The “Aeroelastic Design” programme involves the key issue development and use of aeroelastic codes, computational fluid dynamics (CFD) codes and design tools for wind turbine blades and airfoils as well as wind tunnel measurements of airfoil section flows. The codes are used for establishment of design load basis for wind turbines, further development of the three-bladed wind turbine concept and development of new wind turbine concepts.

The programme “Electrical Design and Control” aims to lower the cost of wind energy by optimising the wind turbine as well as the grid interface and operation of the power system. The research involves topics such as control concepts for wind turbines; electrical components; grid connection and large-scale wind energy penetration; hybrid power supply systems and energy storage combined with renewable energy sources.

The “Wind Turbine” program conducts strategic and applied research in load and safety, experimental verification, technical/economical analysis of wind energy’s utilisation in grids and in hybrid energy systems. Our research within this program supports our consultancy activities for Danish and international authorities, organisations, banks and investors regarding wind energy projects. It also supports our participation in international standardisation.

The special service “Wind turbine and blade testing” offers its expertise in measuring techniques for wind turbines and blade testing. The latter is performed at the new blade test facility at the [Sparkær test centre](#), where we are now able to test blades with a length of up to 40m, both statically and dynamically.

The “Type approval and Certification” service offers type approvals, recommended for wind turbine types in serial production. Type approval is a verification of the wind turbine design according to an [approval scheme](#). This scheme may be extended to cover specific national requirements. This means that Risø can issue type approval certificates according to national rules in Denmark, Germany (Gutachten) and in the Netherlands.

## 4.1 Project results

### Air-sea exchange

The overall project objective is to create a model tool to calculate horizontal and vertical fluxes of nutrients to the North Sea, Kattegat and the Baltic Sea. Risø’s role in the project was to estimate the atmospheric deposition through model calculations. The work is carried out in co-operation with the Department of Atmospheric Environment, National Environmental Research Institute and the project was co-ordinated by the Department of Marine Ecology and Microbiology, National Environmental Research Institute. The project is supported by the Nordic Council of Ministers.

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### ANICE

The overall goal of the ANICE project is to develop a coupled Lagrangian-Eulerian model of atmospheric nitrogen deposition, which includes extended performance of air-sea flux parameterisations and inclusion of heterogeneous processes. There are three tasks in the project: modelling, instrument development, and field experiment.

The experimental efforts in the ANICE project are focused on the collection of data for processes which may not be adequately described by the current models, or for processes for which the estimates are expected to be improved by using experimental data as input. The primary aim of the sampling strategy is to quantify inputs of nitrogen compounds to the southern North Sea; quantitatively describe the processes operating in the marine environment to modify the physics and chemistry of terrestrial air masses as they move over coastal waters. Of specific interest here are processes that modify the particle size distribution and/or phase of nitrogen species.

The first field campaign took place in June 1998, with measurements on Meetpost Noordwijk (MPN: a platform at 9 km off the Dutch coast), and at the Weyborne site in East Anglia (Norwich, UK). Also measurements were made on a ferry cruising between Hamburg, Germany and Harwich, England. At MPN, aerosol particle size distributions were measured with optical particle counters. Concentrations of ammonia and nitric acid and the chemical composition of the aerosols were measured at all three stations. MPN offers a unique opportunity to measure unperturbed fluxes over open sea, by virtue of a boom extending 20 m west of the platform structure. Using this facility, fluxes of nitric acid were directly measured by Risø using the relaxed eddy accumulation (REA) method. This was the first time ever that REA was applied over sea for measurements of fluxes of nitric acid. Support measurements include fluxes of momentum, heat, water vapour and CO<sub>2</sub>.

The project is a co-operation between Risø, National Environmental Research Institute, Denmark, TNO Physics and Electronics Lab., The Netherlands, Hamburg University, Germany and East Anglia University, UK. The project is financially supported by the EU.

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## **ASGAMAGE**

ASGAMAGE is an EC funded project aiming to improve the estimation of air-sea fluxes of trace gases, especially CO<sub>2</sub>, from field experiments and modelling studies. The project, that started in 1996 involves 13 European and two North American groups. Within the ASGAMAGE project, the Risø group participated in both the experiments at Meetpost Nordwijk (MPN) off the Dutch coast and in the modelling studies through partly financing a PhD-project.

The first field campaign, ASGAMAGE-A, took place from 6 May to 7 June in 1996. The second experiment, ASGAMAGE-B, was carried out from 7 October to 8 November in 1997. In both experiments, the Risø group had a close co-operation with the team from TNO. This involved a joint instrument packet to measure the turbulent fluxes of momentum, heat, water vapour and CO<sub>2</sub>. It consisted of a sonic anemometer-thermometer and two Advanet Infra Red absorption instruments to measure the turbulent fluctuations of H<sub>2</sub>O and CO<sub>2</sub>. Two Advanets were used in an effort to improve the signal/noise ratio of the Advanet CO<sub>2</sub> measurements. The year of 1998 has been spent with data analysis and to establish the experimental database for refinement of the exchange formulas. Using Advanet, the most serious problem encountered has been the S/N reduction and uncertainty with the H<sub>2</sub>O-CO<sub>2</sub> cross talk in the instrument.

The modelling study was performed especially to evaluate the role of inhomogeneity and non-stationarity in the air and water for the air-water exchange of different trace gases including of course carbon dioxide as the most important one. The

reason for this objective was that the exchange rate formulation, normally used as a basic assumption, is that the exchange takes place between a well-mixed water body and a well-mixed air body, with the only gradient being present at the interface. To a large extent, the modelling efforts have been performed in co-operation with the group from KNMI. Information on the ASGAMAGE project can be found at: <http://www.knmi.nl/asgamage/>

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### **Atmospheric measurements on Mars**

Risø participated in the NASA Pathfinder mission to Mars in 1997 as a member of the ASI/Met (Atmospheric Science/meteorology) group in the science team. During 1998 the focus of the project has been on the analysis of the data and post-calibration of the velocity sensor, where the data during the mission showed the pre-calibrations to be invalid. The participation of the Risø group is based on the boundary layer meteorological expertise available here. In itself it is interesting to evaluate the models for the structure of atmospheric boundary layers, developed and tested for the parameter combinations characterising the Earth's atmosphere, for the similar atmospheric layers on Mars, which are characterised by different parameter values. However, the boundary layer meteorology also is important when the measurements are used to understand the behaviour of the Martian atmosphere in general. In continuation of the Pathfinder project the Risø group is involved in the Mars Netlander project, that aims to land four Pathfinder-like stations across the surface of Mars. More information about the Mars projects can be found at: <http://sunsite.auc.dk/mars/default.html/>  
[http://www.geo.fmi.fi/boards/NetLander\\_Documents/](http://www.geo.fmi.fi/boards/NetLander_Documents/)

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### **AutoFlux**

The objective of this EC-project is to develop and test in laboratory as well as in the field an instrumentation system "AutoFlux" for routine unattended use on Voluntary Observing Ships (VOS) or unmanned buoys. AutoFlux will automatically produce air-sea flux estimates for the wind stress, buoyancy, heat, water vapour and CO<sub>2</sub>, using high-frequency turbulence measurements. We will utilise improved fast response sensors including a sonic anemometer/thermometer and a dedicated sonic thermometer. A state-of-the-art fast response instrument for routine micrometeorological estimation of water vapour and CO<sub>2</sub> fluxes will likewise be implemented into the system. The system concept is that the fluxes are derived from the turbulence spectra (mainly the so-called dissipation method). This method minimises the effects of flow distortion and platform motion. The system is centred around an improved sonic anemometer/thermometer and employs as well a specific sonic thermometer and a dedicated humidity meter and CO<sub>2</sub> instrument, employing infrared absorption technique. The system software manages the data conversion and storage/transmission as well as the position and orientation of the sensors. More information about the project is available at: [www.soc.soton.ac.uk/JRD/MET/AUTOFLUX/](http://www.soc.soton.ac.uk/JRD/MET/AUTOFLUX/).

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### **BASYS**

The overall goal of the study is to extend the understanding of air sea exchange processes through field studies in order to upgrade parameterisations and high-resolution modelling. Specifically, the objectives for our subproject are:

- to improve the parameterisation of deposition processes in order to estimate the importance of dry deposition;

- to apply sampling strategies that allow a determination of concentration and deposition fields by means of measurements with a temporal resolution of a few days and a basin wide resolution in space.

A field campaign was carried out on the island of Östergarnsholm east of Gotland, a Swedish island in the Baltic. This was the last of three experiments. The experiment started on August 17 continuing until September 4, 1998. Chemical and meteorological measurements were performed more or less continuously when the weather permitted. The field experiments were designed in order to improve the current knowledge about processes near the air-sea interface which involve air-sea exchange of gaseous species and aerosols, as well as new insight on the processes which influence the momentum and heat fluxes.

The Risø work tasks in corporation with National Environmental Research Institute (NERI) consisted of measurements of the fluxes of  $\text{HNO}_3$ ,  $\text{NH}_3$ ,  $\text{SO}_2$ ,  $\text{CO}_2$  and water vapour (the latter two gases are measured to compare to the measurements of the more reactive gases). In addition, micrometeorological parameters to support the flux measurements were also collected.

The project established a co-operation between Risø and NERI, TNO Physics and Electronics Lab., The Netherlands, Uppsala University, Sweden and Indiana University, USA. The project ends in 1999 and is financially supported by the EU-MAST programme.

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### **BEMA and Ulborg**

A relaxed Eddy Accumulation (REA) system to measure biogenic emissions from natural vegetation was developed and tested in 1997. It is generally accepted that these emissions supersede the anthropogenic non-methane hydrocarbon emission, and because of their high reactivity they are important for the tropospheric ozone formation and aerosol budget. In 1998 data from two field campaigns were analysed. One campaign took place in a spruce forest in Western Jutland (DK). In co-operation with the Department of Atmospheric Environment, at National Environmental Research Institute (NERI) volatile organic compound (VOC) was measured during a five-day period. The major emissions found were alpha-pinene and beta-pinene. A strong diurnal variation was observed with a maximum flux at noon up to  $162 \text{ ng/m}^2$  of alpha-pinene. Also a clear temperature dependence of the emissions was found in this study.

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### **COFIN**

A large amount of LIDAR data from previous tracer experiments will be re-analysed and used to develop a stochastic model for concentration fluctuations in gas dispersion. The objective is to provide a natural extension to state-of-the-art dispersion models, which predict only the average concentration field. The work (COFIN project) is supported by EU and done in collaboration with Sheffield University and the System Analysis Department at Risø.

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### **CONFLUX**

The hazards of toxic or flammable gases are usually assessed by numerical dispersion models, which predict only the time-averaged concentration field. The instantaneous concentration fields in a turbulent dispersion process are often very different and the mere average statistics may provide a false impression of the risk, e.g. of gas ignition. The EU-funded project *Concentration Fluctuations in Gas Releases by Industrial Accidents* (COFIN) utilises our collection of data from previous dispersion experiments. It was initialised in 1998 and is done in

collaboration with Sheffield University. The objectives are to extract fundamental statistics on concentration fluctuations, correlate these with meteorological parameters and source-receptor configuration, and finally to develop stochastic models which will supplement or possibly enhance existing dispersion models.

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### **EUROFLUX**

The long-term measurements of carbon uptake by forests have continued within the framework of the EUROFLUX project. The Danish station is located in Lille Bøgeskov near the town of Sorø. The method used is the so-called eddy-covariance method. The net ecosystem exchange (NEE) is in a delicate balance between the photosynthetic assimilation (approximately 1000 gC/m<sup>2</sup>/year) and the ecosystem respiration processes. The assimilation as well as the respiration is dependent on the environmental variables such as solar radiation, air and soil temperature and humidity, but in a different way. For the growing season 1996-97 the carbon uptake was 171 gC/m<sup>2</sup> while in 1997/98 it was 132. The lower value in the 97/98 season has the following interesting explanation: in spite of a warm and sunny summer in 1997, which resulted in a photosynthetic assimilation larger than that of the previous season, it was outran by the temperature dependent respiration. The year to year variation in the carbon sums is of importance for the assessment of forests as long-term carbon sinks under changing climatic conditions.

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### **Experimental meteorology**

The objective is to perform research-based implementation of meteorological measurements to be used in boundary-layer experiments and long-term monitoring work. Some of the activity is carried out in connection with the departmental programme research and some for external clients. The work is carried out on programme-research or commercial terms dependent on the nature of the individual task.

EME activities are divided into three broad categories. One is development and maintenance of instruments and data systems. Another is operation of measuring stations. This means stations that are not dedicated to specific programs, but where long-term reliable climatology measurements are the key facets. Last but not least participation in the experimental and monitoring parts of many of the projects undertaken by the other programs of the department. Many EME activities therefore are included in the description of experimental projects presented within the headings of the other programs of the department.

One aspect of these measuring campaigns could be emphasised. The year 1998 was the first year where the developed capability of on-site data analysis of larger field campaigns was successfully applied. This means that when an experiment is dismantled, all of the raw analysis has been conducted, and not only the measurements themselves.

Also 1998 was the first year where data from many of the measuring stations operated by EME were transmitted on the Web to facilitate data control of remote stations, but also simply to make the data available for co-operators and the public.

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## **HILLCLOUD**

A delicate balance between incoming and outgoing radiation determines the temperature of our planet. It has been speculated that anthropogenic aerosol forcing is the reason why the increased of atmospheric CO<sub>2</sub> content does not lead to more global warming – or, in other words, that air pollution alters the optical properties and make it reflect more solar light, e.g. by enhanced cloud formation. The purpose of the *Second Aerosol Characterisation Experiment* (ACE-2) organised by IGAC was to study marine aerosols in an area with occasional pollution. This was chosen to be the Atlantic region south west of the Iberian Peninsula. The EU-funded HILLCLOUD project (1996-1998) was part of this large experiment and utilised the frequent hill cap cloud formation over a mountain ridge in Tenerife to quantify the aerosol distribution and composition by land-based measurements. Comparisons between measurements in unsaturated air on the upstream and downstream of the hill and the cloud at the summit provided information on water deposition on the particles and complex chemical reactions which took place inside the liquid aerosols. The role of Risø was to detect the flow over by meteorological masts and radio sondes. The terrain was quite steep and had a marked effect on surface wind. We detected phenomena like stability induced downdrafts on the leeward side, catabatic winds, and flow separation which made the leeward surface wind reverse.

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## **Implementing short-term prediction at utilities**

This multi-partner, multi-country EU-JOULE funded project completed on time at the end of 1998. The project succeeded in implementing on-line two wind-farm systems for production prediction at electrical utilities. One system was developed by Risø, and the other by IMM at the Danish Technical University. The two Danish utilities Elsam/Eltra and Elkraft are using the systems in their daily planning and dispatch with very good results. The economic benefits were calculated by Rutherford Appleton Laboratories in the UK and the calculations showed that monetary benefits could indeed be obtained by using prediction systems in the daily dispatch. National Observatory of Athens in Greece implemented models for wind farms on Crete. Electrical Power Research Institute (EPRI) in the US also participated and a few sites in the US were calculated off-line.

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## **Java Puff (web-based Rimpuff)**

[See: [http://www.risoe.dk/vea-atu/atm\\_disp/rimpuff/javapuff/online.html](http://www.risoe.dk/vea-atu/atm_disp/rimpuff/javapuff/online.html)]

To visualise the potential in real-time on-line internet based IT in service for emergency response and decision support, a simplified version of the local-scale puff dispersion model RIMPUFF can now be seen “live” on the URL listed above (Risø’s home page). Here RIMPUFF runs as a Java applet that shows - in real time - the actual position and size of a “live” puff plume being released from the local met-tower. A detailed description can be found on the Java Puff home-page links.

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## **LUMINY**

The Luminy project involves seven European groups. It is based on EC-funding and was initiated in 1996. The focus of the project is an experimental study of the water-air gas exchange. It takes place in a large wind-water tunnel of the

IRPHE institute at University of Marcella at Luminy. Especially, the effect of air bubbles and water spray on the transfer processes has been determined and parameterised. The main Risø contribution to the Luminy project has been participation in measuring and analysis of the structure of fluxes, wind and temperature turbulence, just over the water surface in the tunnel. The Risø group participated in the Luminy pilot experiment in September 1996, in the main experiment, March-April 1997t and participated as well in the project meteorological data analysis.

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### **Measure-correlate-predict**

Presently there are two methods for estimating the wind resource at a potential wind farm site: the wind atlas methodology (WAsP) and a method called measure-correlate-predict (MCP). A JOULE funded project was initiated to develop new MCP-methodologies, the project is co-ordinated by RES in the UK, Ecomtec and Risø are project partners. The main idea of the project is to develop methods which use neural networks and University of Sunderland has been involved in the design and programming of such methods.

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### **NATO/CCMS ITM conference series**

Since 1992 Risø has chaired this conference series, dealing with air pollution modelling and its application. The 23<sup>rd</sup> ITM conference took place in the period 28 September to 2 October in Bulgaria, hosted by the National Institute of Meteorology and Hydrology, Bulgarian Academy of Sciences. Participants in a number of 120 from 30 countries attended the conference. The concept of regular NATO/-CCMS International Technical meetings has evolved into a tradition of bringing together experts to discuss application of existing air pollution models and the development of new models to meet emergency needs. The conference series has provided a basis for considerable advance in the areas of model development and validation. The presentations are generally of a very high quality, dealing with applied as well as new concepts and trends in air pollution modelling, public and regulatory policies. The ITM conference series has always had a strong spirit of co-operation under the NATO/CCMS umbrella, and with considerable interest from partner countries to participate in the ITM conferences, it provides an excellent opportunity to create ties between scientists from NATO and Co-operative partner countries.

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### **NEAREX**

The objective of the project is to study the origin, variability and air/sea fluxes of CO<sub>2</sub> and atmospheric particulates over the North East Atlantic Region (NEAR). The study is carried out by measuring the CO<sub>2</sub>-concentration in water and air, and the amount of particulate matter in the near surface air; deriving local area average surface fluxes of CO<sub>2</sub> and particulates at selected locations within NEAR.

An equilibrator was constructed to carry out measurements of CO<sub>2</sub>-concentrations in the water and air in order to calculate the difference of the partial pressure of CO<sub>2</sub> between air and water ( $\Delta p_{CO_2}$ ). The equilibrator was used in a cruise in the NEAR in November-December 1998. At the same cruise we measured CO<sub>2</sub>-fluxes in the atmosphere by the use of a LICOR, which is a fast responding optical monitor (20Hz), where the analyses are based on IR absorption, and a sonic anemometer. The project is a co-operation between department of Wind Energy and Atmospheric Physics, Risø National Laboratory,

Department of Atmospheric environment, National Environmental Research Institute, Department of Geophysics and Department of Chemistry, Copenhagen University and Danish Meteorological Institute. The project is financial supported by the Danish Scientific Research Council.

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### **NOPEX**

The problem of spatial integration of land surface parameters over a non-homogeneous land surface and especially the estimation of regional (grid) surface fluxes is a central issue for the NOPEX intensive experimental campaigns carried out in 1994 and 1995. The NOPEX region is situated near Uppsala in Sweden. It consists of surface elements of coniferous/mixed forest and agricultural land with scattered mires, lakes and urban areas. A method to derive the direct integrated sensible heat flux from information on the evolution of the mixed layer based on radio soundings has been developed and applied for the NOPEX area. The regional heat flux was found to be lower than the heat flux over forest and higher than the heat flux over agricultural fields. The regional heat flux estimated by the mixed-layer evolution method was compared to a land-use-weighted average heat flux. The two independent estimates of the regional heat flux were found to be in general agreement. The results from the NOPEX field campaigns will be published in a special issue of agricultural and forest meteorology.

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### **Numerical wind atlas – the KAMM/WAsP method**

Risø is developing a method to make wind atlases in the WAsP format from numerical meso-scale simulations. This is to complement WAsP, which relies mainly on measured surface winds, with a method which can take advantage of global data bases of the large scale wind and pressure field, which already exist. This will allow a first estimate of the wind resource in regions of no or only poor surface observations. Also, a good regional overview can be obtained. The project is funded through the Danish Energy Research Program and is running for three years.

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### **Offshore wind resources**

At the end of 1997 a new mast was installed at Middelgrunden bringing the number of meteorological masts operated under the Danish Offshore Wind Monitoring Program to eight in total. Funding for the operation and maintenance of the masts and analysis of the meteorological data is from a number of sources including the European Union Joule Program, the Danish Energy Ministry and SEAS/ELKRAFT.

Data from the offshore masts were used to determine wind resources at the prospective offshore wind farm sites and to characterise offshore wind and turbulence climates. Two projects focused on analysis of these data successfully concluded this year; the European Commission Joule Program project 'Cost optimisation of large wind turbines' and the Danish Energistyrelsens Udviklingsprogram for Vedvarende Energi project 'Offshore wind resources'.

The offshore monitoring and analyses are ongoing. Data from the Middelgrunden mast was presented at a public meeting to discuss the wind farm in Copenhagen Town Hall in August. A new modelling project was initiated through European Commission Joule Program 'Predicting Offshore Wind Energy Resources' (POWER). POWER aims to reduce uncertainties in offshore wind re



source estimates for Europe through use of long-term data sets and with improved coastal models.

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### **OMEX**

The EC-OMEX projects are a sequence of projects aiming to determine the carbon budget for the European marginal seas. In OMEXI, the Risø group has been involved in experimental determination of the air-sea fluxes of CO<sub>2</sub> by the micrometeorological methods from ship cruises. In OMEXII the group is engaged in determination of the flux from measurements of the air-sea difference in partial pressure of CO<sub>2</sub>, especially taking into account the inhomogeneity and inhomogeneity often characterising the processes in the coastal zone.

Overall, the micrometeorological methods have been found to deliver results that are getting closer to the average of the transfer-velocity method during the OMEX cruises. However the method is still in the development phase. Both the sonic and the CO<sub>2</sub> systems used were found to perform less well than expected and desired. In a PhD study the surface fluxes transient situations have simultaneously been studied by means of simple diffusion models combined with the description of the carbonate buffer system. Although simplistic, this modelling concept allow for both exploratory and production analysis of the air-ocean exchange of CO<sub>2</sub>. It has been found that for CO<sub>2</sub> only very small scale strong inhomogeneities cannot be treated as pseudo-homogeneous. More information about the OMEX projects can be found on the address: <http://www.pol.ac.uk/bodc/omex.html/>

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### **PEP in the Baltic Sea**

The general purpose of the project is to be a precursor for the main BALTEX field experiment scheduled for year 2000. PEP in Baltic will concentrate on evaluation of techniques for measuring evaporation and precipitation over the Baltic Sea, and to provide a comprehensive set of actual evaporation and precipitation data at four sites over the Baltic Sea area, covering a total of 18 months. The main activity of Risø National Laboratory is to participate with meteorological measurements of momentum, heat and water vapour fluxes. The measurements are performed at Ertholmene, a small group of Danish islands in the Baltic Sea east of Bornholm (15° 12' E, 55° 19' N). The measurements were started on April 22, 1998, and have been performed near continuously. It should be noted that access to Ertholmene is cumbersome, making service on the instruments difficult and time consuming. Preliminary results shows, that the bulk parameterisations used in operational meteorological forecasts models overestimate the evaporation from the Baltic Sea with about a factor of two, therefore there is a considerable interest for these data

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### **RODOS-2000**

As concerns atmospheric dispersion, RODOS-2000 aims at developing an IT based decision tool for the European countries by the end of the year 1999. This is one of the demands to the programme in Risø's contract with the ministry. The system contains and controls all of the atmosphere programmes that are relevant in case of a nuclear accident within a distance of 40 kilometres from a nuclear power plant, and it includes chains of dispersion meteorological and irradiation dose models. The Danish Emergency Management has a similar system called ARGOS-NT that is used in Denmark, the Baltic States and Po-

land. In 1997 Risø has worked with both systems. To a certain extent they apply the same programmes, and both systems are operational.

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### **RTMOD**

An EU sponsored Concerted Action (CA) named RTMOD after real-time model inter-comparison has been launched under the EU DGXII Radiation Protection Research Programme. The activity inter-compares dispersion model predictions on the European scale in real time using WEB technology. The MET-RODOS module for real-time atmospheric dispersion predictions of accidental releases on the European continent participates in this real-time prediction exercise.

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### **Russian Wind Atlas**

The work on the Russian Wind Atlas continued in 1998. More than 200 stations covering all of Russia have been analysed according to the Wind Atlas Methodology by the Russian Danish Institute for Energy Efficiency (RDIEE) in Istra near Moscow. The role of Risø is to act as a consultant and to assure the quality of the analysis. The Danish Ministry of the Environment and Energy finances the project.

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### **SFINCS**

This EU project aims to implement improved atmospheric boundary-layer parameterisations into climate models. It especially aims to improve the parameterisations for convective and stable conditions. In connection with the project the conventional Monin-Obukhov scaling approach has been extended for the stable atmospheric surface layer. The Brunt-Vaisala frequency of the free troposphere has been included in the set of basic parameters in this extension. The approach preserves the log-linear profiles but with coefficients now varying with the parameter  $S = N \cdot L/u_*$  where  $N$  is the Brunt-Vaisala frequency while  $L$  and  $u_*$  are the Monin-Obukhov scale and the surface stress respectively. The turbulent Prandtl number is found to increase with the Richardson number. The new scaling approach has been validated against night-time data from Greenland and has been successfully applied also to the HIRLAM model of the Swedish Meteorological and Hydrological Institute.

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### **Short-term prediction Germany**

In connection to the EU-JOULE project "Implementing short-term prediction at utilities" an add-on project was started in 1998. Two German institutes as well as Risø are the project participants. The idea is to transfer and refine the model developed in the above project and apply it to German conditions. It is important to use these models in Germany, since Germany is the European country with the highest installed capacity. The two German partners are University of Oldenburg and Fachhochschule Magdeburg.

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### **State-of-the-art wind resource estimation**

To estimate the wind resource/power production at a specific location there is a number of methods, that today can be labelled, state-of-the-art. All these methods build on the Risø WAsP (Wind Atlas and Analysis Program) model, which today is considered the industry standard in wind resource estimation. The simplest case involved the use of only the WAsP program with input of data from a near-by-meteorological station. If the terrain gets complex (or very hilly) the

WAsP program should be used in combination with the so-called Raggedness Index (or RIX number) - this number (or rather the difference in this number) gives the correction factor to be applied to the WAsP result.

If the wind resource in a larger area is needed, a combination of a meso-scale model (as the Karlsruhe meso-scale model KAMM) and WAsP is considered the best solution. The meso-scale models model atmospheric flow on scales which are not modelled by (the micro-scale model) WAsP. This makes the marriage of these two models a very clever one, where scales from the very small (1-10 m) up to the very large (50-500 km) are modelled in the same model complex.

If only very rough estimates are needed, the publicly available databases on global distributions of the wind can be used either directly or in combination with a meso-scale model (e.g. KAMM) to give a first estimate of the regional resource.

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### **WAsP**

Risø's WAsP software package is the industry standard tool to estimate wind resources. More than 460 copies have now been sold in over 60 countries. The software is under continual development in co-operation with the Danish wind turbine industry and the international research community. A Windows version is expected to be ready early 1999.

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### **WAsP consultancy and courses**

A number of Second opinion/Due diligence studies were carried out for wind farm investors and developers. These studies are seen as a service to the industry and to help Risø improve the wind farm production estimation tools WAsP and PARK. As a support function to the many WAsP customers the annual two-day WAsP course was also held, participants came from all of Europe and from industry and consulting companies.

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### **WAsP for windows**

The main event in the wind resource estimation area in 1998 was the initialisation of a project, which had as its goal to develop a new version of the WAsP program, which would run under Windows. The actual programming and design of the graphical user interface were out-sourced to two professional software houses: World in a Box and Lambda Soft. The design phase and most of the programming were completed in 1998 and the official launch was scheduled for the European Wind Energy Conference in Nice in 1999.

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### **Waves and sea roughness modelling**

In a series of co-operative project between DHI, Risø and DMI funded by the Danish Technological Research Councils, the partners have worked on improving the modelling of the momentum transfer between the atmosphere and the ocean. This especially concerns coastal and landlocked sea, where the final fetch effects are anticipated to be important. The effort has aimed to improve both the performance of WAM (WAVE Models) models for such waters and conversely improve the surface roughness estimations for these waters. The deficiencies of standard WAM for coastal waters have been demonstrated using the models of DHI and data from the offshore site at Vindeby, run by Risø. A

parameterisation scheme based on an improved wave-roughness coupling is being implemented.

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### **Wind Atlas for Egypt**

In 1998 the Wind Energy and Atmospheric Physics Department embarked on one of its largest wind resource assessment projects ever: a Wind Atlas for Egypt. The purpose is to analyse, model and map the wind resources of Egypt – an area of about one million square kilometres – using meteorological measurements, state-of-the-art wind flow models and satellite imagery. Fourteen new wind-measuring stations are being erected as part of the project, bringing the total number of Risø-designed stations in operation in Egypt to about 23.

The project is funded by the Danish and Egyptian governments and carried out in collaboration with the Egyptian Meteorological Authority and the New and Renewable Energy Authority (NREA) in Cairo. Risø's contract is with the Danish Ministry of Foreign Affairs and it was negotiated directly with Danida – based on Risø's previous experience and projects in wind-atlas studies in general and in Egypt in particular. From 1991 to 1996 Risø carried out an investigation of the wind resources in the Gulf of Suez and together with NREA we published a wind atlas, which proved this area to be one of the most promising regions in the world for wind energy utilisation.

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### **WINTEX**

As a part of WINTEX, meteorological measurements were carried out at Sodankylä (67° 29' N, 26° 39' E) in Finnish Lapland March 1997 in order to study the feasibility of applying sonic anemometers for turbulence measurements during winter conditions. Also fluxes of incoming radiation, heat and humidity over a boreal forest typical for the Northern hemisphere are investigated. The measuring site is located in a sparse forest of typically 6-8 metre tall pine trees. The measurements represent harsh winter conditions characterised by low sun angles. The absorption of incoming solar radiation (turgidity) was found to be a strong function of the solar elevation. Commonly used expressions for the absorption did not fit the measurements well at these low solar elevation angles. It was found that the heating of the trees controlled the heat flux during daytime. A simple energy balance type met-processor was found to perform well during daytime. The performance during night-time was not satisfactory, indicating that the night-time heat flux is controlled by the energy balance in the snow pack on the surface.

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# 5 Co-operation and Dissemination

## 5.1 Partners and co-operation

Successful research utilisation is of paramount importance for the department. Stake holders (clients) and parties interested in our research can be divided into three categories:

- Industry
  - wind power industry
  - consultancy
  - power utilities
- Authorities
- national (eg Danish Emergency Management Agency, Danish Environmental Protection Agency, Danish Energy Agency, DANIDA, Danish Veterinary and Food Administration)
- European (eg EU, CEC, CEN/CENELEC)
- international (eg WMO, IEA, IEC, UN, the World Bank)
- Scientific communities
- universities and research laboratories (eg Danish Institute of Plant and Soil Science, AAU, DTU, KU, NCAR (USA), NREL (USA), ECN (The Netherlands), DEWI (Germany), CRES (Greece), CIEMAT (Spain), Karlsruhe University (Germany), EUREC-Agency)
- PhD programmes

The department makes use of a number of channels to interact with these stake holders:

- direct dialogue
- direct co-operation on R&D projects under Danish and European R&D programmes
- international conferences
- international standardisation
- research based type approval activity
- research based turbine and blade testing activity
- publications
  - informal but fast (fax information to industry and other users)
  - research reports (both public and internal/confidential)
  - standards and guidelines
  - conference contributions
  - papers in peer reviewed journals

The department is involved in a number of research projects in co-operation with partners from industry and other private or semi-private enterprises. Among these are A/S Wincon, ABB, Bonus Energy A/S, Carl Bro A/S, COWI A/S, Dahl Instruments, Dan Service A/S, Danish Standard, DEFU, Danish Slaughterhouses, Det Norske Veritas A/S, DMI, DMU, DTI, Elkraft, Elsam, EPP (Greece), Garrad & Hasan (UK), Genvind Production, Kampsax A/S, LM Glasfiber A/S, N.E.G. Micon A/S, MST, Great Belt Connection A/S, Svendborg Brakes A/S, Vestas Wind Systems A/S, WEA A/S, WindWorld of 1997.

### **Direct dialogue with industry**

Before the 1997 round of submitting proposals to the Danish Energy Research Programme '98, the head of the department, the deputy head and the head of two of our research programmes paid a visit to a number of Danish wind turbine companies. The director of the Association of Danish Wind Turbine Manufacturers attended the visit. The purpose of the visit was to discuss future research projects and possibilities for co-operation. The team had discussions with the chief executives of the companies and heads of their R&D departments.

### **Risø Wind Day '98**

Risø wind day is an annual event with presentation of an updated overview of part of our expertise and activities within the wind energy field to an invited audience among our key stake holders. In 1998 this event took place on 27 November.

## **5.2 Programme participation**

Programme participation is the most significant contribution to the department's R&D turnover.

On a national level the department participates in the Energy Research Programme (EFP), Development Programme for Renewable Energy (UVE), Environmental Research Programme (SMP) and projects under the governmental technical research council (STVF). The total financial frame of these programmes (especially the research part) is increasing. For most contracts part of the funding is transferred via Risø to other partners, sub-contractors and consultants.

On a European level the department has had great success in obtaining contracts under a number of EU research programmes among which are JOULE, THERMIE, EUREKA, MAST, ENV, SMT and APAS. The department also participates in projects under Nordic Council's research programme.

On an international level (outside EU) no available research funding exists. International co-operation is co-ordinated through the wind energy R&D agreement of IEA, but funded through national programmes. In 1997 the department participated in an IEA organised Round Robin test of an American wind turbine. The department also participated in several workshops and expert meetings arranged under the IEA Wind Energy R&D Agreement.

## **5.3 Committee and Expert Group Memberships**

Christensen, C.J., *Chairman*, International Electrotechnical Committee, Technical Committee 88, Wind Turbine Systems

Christensen, C.J. Dansk Elektroteknisk Komite, DEK. Teknisk Udvalg 88 (TU88) Sikkerhed af Elproducerende Vindmøller (Danish Electrotechnical Committee, Technical Committee TU88, Safety on Wind Turbine Generator Systems)

Christensen, C.J. International Electrotechnical Committee (IEC). Technical Committee 88 (TC88) Safety of Wind Turbine Generator Systems, Working Group 17

Christensen, C.J. *Chairman*, European Standards for Wind Turbines, CENELEC BTTF 83-2

Dannemand Andersen, P. Danish Energy Council, Co-ordination Group on Wind Energy

Dannemand Andersen, P. Danish Energy Council, Technical Committee on Certification and Type Approval

Dannemand Andersen, P. Danish Energy Council, Advisory Committee on Certification and Type Approval

Dannemand Andersen, P. International Energy Council, Implementing Agreement on Wind Energy (IEA R&D Wind), Executive Committee

Dannemand Andersen, P. *Chairman*, International Energy Council, Implementing Agreement on Wind Energy (IEA R&D Wind), Strategy Committee

Frandsen, S. Steering Committee for Egyptian-Danish Collaboration Project on Wind Energy

Frandsen, S. Dansk Elektroteknisk Komite, DEK. Teknisk Udvalg 88 (TU88) Sikkerhed af Elproducerende Vindmøller (Danish Electrotechnical Committee, Technical Committee TU88, Safety on Wind Turbine Generator Systems)

Frandsen, S. International Electrotechnical Committee (IEC), Technical Committee TC88, Working Group 6, Test Procedures for Wind Turbine Testing

Friis Pedersen, T. Danish Energy Council, Technical Committee on Certification and Type Approval

Friis Pedersen, T. Dansk Elektroteknisk Komite, DEK. Teknisk Udvalg 88 (TU88), Sikkerhed af Elproducerende Vindmøller (Danish Electrotechnical Committee, Technical Committee TU88, Safety on Wind Turbine Generator Systems)

Friis Pedersen, T. *Chairman*, International Electrotechnical Committee (IEC), Technical Committee TC88, Working Group 6: Test Procedures for Wind Turbine Testing

Friis Pedersen, T. Danish Energy Agency, Technical Committee (IEC), Technical Committee on Certification and Type Approval

Friis Pedersen, T. *Convenor*, International Electrotechnical Committee (IEC), Technical Committee 88 (TC88) Power Performance Measurement Procedures

Gryning, S.E. *Deputy Chairman*, Danish Meteorological Society (DAMS)

Gryning, S.E. *Honourable Secretary*, European Association for the Science of Air Pollution (EURASAP)

Gryning, S.E. *Chairman*, Executive Committee, NOPEX

Gryning, S.E. International Scientific Committee on the 5<sup>th</sup> International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes

Gryning, S.E. International Scientific Committee on the 6<sup>th</sup> International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes

Gryning, S.E. *Chairman*, Scientific Steering Committee on NATO/CCMS International Technical Meetings on Air Pollution Modelling and Its Application, Conference Series

Gryning, S.E. COST Action 710. Processing of Meteorological Data for Dispersion Modelling. Working Group 2: Mixing-Layer Depth Determination for Dispersion Modelling

Gryning, S.E. Science Panel on Atmospheric Chemistry Research (DG XII, EU)

Gryning, S.E. International Scientific Committee on the Stable Boundary Layer Workshop, Sweden, October 1997

Gryning, S.E. *Guest Editor*, Atmospheric Environment, Special Issue of the MEDCAPHOT Trace Experiment

Gryning, S.E. *Guest Editor*, Journal of Agriculture and Forest Meteorology. Special issue of the NOPEX experiment

Harvøe, P. Danish Energy Council, Technical Committee on Small Wind Turbines

Harvøe, P. Danish Energy Council, Promoter Committee on Small Wind Turbines

Harvøe, P. Tønder Technical School, Educational Wind Farm

Hasager, C.B. Corps of External Examiners, University of Copenhagen

Hasager, C.B. *Co-convenor*, European Geophysical Society at Symposium on Soil-Vegetation Atmosphere Transfer Schemes in GCMS

Hasager, C.B. *National EC-representative*, DG VI, working group on Remote Sensing Applications on Forest Health Assessment

Højholdt, P., Danish Energy Council, Promoter Committee on Small Wind Turbines

Hauge Madsen, P. *Chairman*, Dansk Standard (DS). Teknisk Udvalg S588, Sikkerhed af Elproducerende Vindmøller (Danish Standard, Technical Committee S588, Safety of Wind Turbine Generator Systems)

Hauge Madsen, P. *Chairman*, International Electrotechnical Committee, Technical Committee 88 (TC 88), Safety of Wind Turbine Generator Systems, Working Group 7, Revision of Part 1: Safety Requirements

Hauge Madsen, P. *Chairman*, International Electrotechnical Committee (IEC). Technical Committee 88 (TC88), Safety of Wind Turbine Generator Systems, Working Group 9: Certification Procedures of Wind Turbines

Hauge Madsen, P. International Electrotechnical Committee (IEC). Technical Committee 88 (TC88)

Hauge Madsen, P. European Standards for Wind Turbines, CENELEC BTTF 83-2

Hauge Madsen, P. *Board Member*, Fuel and Combustion Technology Association, Danish Society of Chemical, Civil, Electrical and Mechanical Engineering (IDA)

Hauge Madsen, P. *Editorial Board*, "Wind Energy", Wiley & Sons

Hjuler Jensen, P. International Electrotechnical Committee (IEC). Technical Committee 88 (TU88), Safety of Wind Turbine Generator Systems

Hjuler Jensen, P. Dansk Elektroteknisk Komite, DEK. Teknisk Udvalg 88 (TU 88) Sikkerhed af Elproducerende Vindmøller (Danish Electrotechnical Committee, Technical Committee TU 88 Safety on Wind Turbine Generator Systems)

Hjuler Jensen, P. *Chairman*, Danish Energy Council, Committee on Criteria for Design and Certification of Wind Turbines, Working Group 17: Operation and Maintenance

Hjuler Jensen, P. Danish Energy Council. Technical Committee on Criteria for Design and Certification of Wind Turbines. Working Group on Control and Safety Systems for Wind Turbines

Hjuler Jensen, P. *Convenor*, International Electrotechnical Committee (IEC), Technical Committee 88 (TC 88) Safety on Wind Turbine Generator Systems, Working Group 17

Hjuler Jensen, P. *Secretary*, European Wind Energy Association (EWEA), Corporate Group

Hjuler Jensen, P. Danish Energy Council. Wind Energy Advisory Committee

Hjuler Jensen, P. Danish Energy Agency, Wind Energy Research Committee (DK)

Hjuler Jensen, P. European Standards for Wind Turbines, CENELEC BTTF 83-2

Hjuler Jensen, P. European Wind Energy Association (EWEA). Corporate Group



Hummelshøj, P. *Secretary*, Nordic Society for Aerosol Research (NOSA)

Hummelshøj, P. International Advisory Organisation Committee, The Aerosol Society

Højholdt, P. Danish Energy Council, Promoter Committee for Small Wind Turbines

Højholdt, P. Technical Committee for Domestic Wind Turbines

Jensen, N.O. European Geophysical Society. *President of Meteorology*, Oceans and Atmosphere (OA)

Jensen, N.O. *Secretary*, Steering Committee, Danish Centre for Atmospheric Research (DCAR)

Jensen, N.O. National Committee of IUTAM (International Union of Theoretical and Applied Mechanics)

Jensen, N.O. National Committee for the International Geosphere-Biosphere Programme (IGBP)

Jensen, N.O. *Editorial Board*, Boundary-Layer Meteorology

Jensen, N.O. *Chairman*, Boundary Layer Dynamics and Air-Sea Interaction. Working Group A, under ICDM/IAMAS (International Commission on Dynamic Meteorology/International Association of Meteorology and Atmospheric Physics)

Jensen, N.O. *Secretary*, International Commission of Dynamic Meteorology (ICDM)

Jensen, N.O. *Associate Editor*, Quarterly Journal of Royal Meteorological Society

Jensen, N.O. Expert Group Geoscience, Swedish Natural Science Research Council

Kristensen, L. *Associate Editor*, Quarterly Journal of Royal Meteorological Society

Krogsgaard, J. *Editorial Committee*, European Small Hydro Power Association (ESHA), Atlas of European Small-Scale Hydropower Potential

Krogsgaard, J. *Editorial Committee* European Small Hydro Power Association (ESHA), Layman's Guidebook on how to develop a small hydro site

Krogsgaard, J. *Editorial Board*, JWB Study on Hydro Power

Landberg, L. Steering Committee of Off-shore Wind Energy Network, UK

Larsen, S.E. National Committee for the International Geosphere-Biosphere Programme (IGBP)

Larsen, S.E. Committee on the Marine Aerosol and Gas Exchange Project of the International Global Atmospheric Chemistry Program

Larsen, S.E. National Committee for Climate Research. Danish Committee of the World Climate Programme

Larsen, S.E. Scientific Committee of EUROTRAC2

Larsen, S.E. Steering Committee, EUROTRAC2-CAPP Project

Lundtang Petersen, E. EUREC-Agency EEIG

Lundtang Petersen, E. *Editorial Board*, International Journal of Solar Energy

Lundtang Petersen, E. *Editor*, "Wind Energy", Wiley & Sons

Lundtang Petersen, E. *Chairman*, 1999 European Union Wind Energy Conference and Exhibition, 1 - 5 March 1999, Nice, France

Mikkelsen, T., *Board Member*, RODOS Management Group RMG, Radiation Protection Research Programme EU, DG-XI/XII

Mikkelsen, T. *Work Group Leader* for Atmospheric Dispersion within the RODOS real-time Decision Support System, EU, DG-XI/XII

Mikkelsen, T., International Scientific Committee on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes

Mikkelsen, T., *Administrative Co-ordinator*, EU Concerted Action Program on Real-time Models for Intercomparison (RTMOD)

Mikkelsen, T., *Convenor*, European Geophysical Society (EGS) - Mesoscale Transport and Diffusion

Mortensen, N.G. Nordic TeX Committee

Mortensen, N.G. Quality Control Committee on Exhibition on Energy Production and Environment

Mortensen, N.G. Corps of External Examiners, University of Copenhagen

Rasmussen, F. *Editorial Board*, “Wind Energy”, Wiley & Sons

Skamris, C. International Electrotechnical Committee (IEC), Technical Committee TC88, Working Group 9: Certification Procedures of Wind Turbines

Skamris, C. Danish Energy Council, Technical Committee (IEC), Technical Committee on Certification and Type Approval

Søndergaard, L. *Editorial Board*, “Wind Energy”, Wiley & Sons

Sørensen, P. International Electrotechnical Committee (IEC), Technical Committee TC88, Working Group 10

Thylier-Nielsen, S. Ad Hoc Group on the NEA/CEC Intercomparison Exercise on PCA Codes

Vignati, E. Association for Aerosol Research (GaeF)

Winther-Jensen, M. Advisory Committee on Insurance, The Danish Wind Power Utilities

Winther-Jensen, M. Transmission Technical Advisory Committee (GIG)

Winther-Jensen, M. International Electrotechnical Committee (IEC). Technical Committee 88 (TC88), Working Group 8, Testing of Rotor Blades

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- Hansen, A.; Bindner, H. (1998) Three-bladed wind turbine with dual control - strategies for change limits in power reference. Risø-I-1336(DA), 22 pp.
- Hansen, J.C. and N.G. Mortensen (1998). Wind Atlas Analysis and Application Programme in Indonesia. Aide Memoire, mission 14-28 February 1998 - preliminary findings and recommendations. Prepared for United Nations. Risø-DOK-565(UNOPS-INS-1320A), 14 pp.
- Hansen, J.C. and N.G. Mortensen (1998). Wind Atlas Analysis and Application Programme in Indonesia - final report. Prepared for United Nations. Risø-DOK-567, vp.
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- Rathmann, O. (1998) Wind atlas analysis for 12 meteorological stations on the Kola Peninsula. Risø-I-1285(EN), 36 pp.
- Schaarup, J.H. (1998) Type approval rules in The Netherlands. Risø-I-1266(DA), 20 pp
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- Sørensen, P. (1998) Power quality test of Bonus 600 kW wind turbine. Risø-I-1366(EN), 20 pp.
- Zilitinkevich, S.; Larsen, S. (eds) (1998) First meeting on SFINCS 1, Roskilde (DK), 11-12 February 1998. Risø-I-1245(EN) vp
- Ømann Lind, S. (1998) Wind turbine test: NEG-Micon M-1800 750-kw LM 23.5 (C1800-238) dynamic response at stand still. Vestrup, Randers (DK). Risø-I-1202(EN), 12 pp.
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## 6.8 Educational activities

- Mann, J. (1998) Lecture notes for the PhD course on experimental fluid dynamics and data interpretation, Danish Technical University (DK), 19-28 August 1998, 20 pp.

## 6.9 Seminars held in the department

- Bergmann, J. "Geostrophic drag coefficient and boundary layer height determined from the momentum balance of idealised neutral and stable planetary boundary layers" (April)
- Evans, Jenni "Aspects of weather - climate in the convective tropics (February)
- Friborg, Thomas " Eddy correlation measurements of methane exchange in high arctic Greenland" (April)
- Grachev, Andrey "Convective profile constants revisited" (July)
- Jones, Ian "Ocean nourishment, global carbon dioxide control?" (October)
- Khalaji, Morteza "Perspectives for wind energy utilisation in Iran", The Test Station for Wind Turbines (February)
- Sorbjan, Zbigniew "Large eddy simulations of atmospheric convection in the nocturnal and daytime boundary layers" (June)
- Tsinober, Arkady "On depression of non-linearity" (September)
- Wilson, David "Simulating concentration fluctuation time series in atmospheric plumes from accidental toxic and flammable releases" (June)

Wilson, David "Non-Gaussian concentration profiles in relative dispersion" (September)

Yaglom, A.M. "Turbulence characteristics in an unstably stratified surface layer and the influence of large-scale structures" (July)

Yaglom, A.M. "Tensor of turbulence diffusivities in neutrally and non-neutrally stratified surface layers; its form and numerical values" (July)

Zecchetto, S., "Wind stress in the marine surface layer detected by SAR", November

Zilitinkevich, S. "A theoretical model for distribution and transport of suspended particles in planetary boundary layers (March)

## 7 Staff and Guests

### 7.1 Staff

#### **Administration**

*Madsen, Peter Hauge, Deputy Department Head*

*Petersen, Erik Lundtang, Department Head*

#### **Secretaries**

Christiansen, Ulla Riis

Clausen, Gitte (on leave from 9 September 1998)

#### **Programme: Wind Turbines**

##### **Scientific staff**

Andersen, Per Dannemand (till 31 May)

Christensen, Carl Jørgen

Frandsen, Sten Tronæs

Hansen, Jens Carsten

Harvøe, Per

Højholdt, Poul

*Jensen, Peter Hjuler, Programme Head*

Jørgensen, Erik Rosenfeldt

Krogh, Thomas (from 1 January)

Nørgaard, Per (on leave till 1 October)

Thøgersen, Morten Lybech (from 1 January)

Winther-Jensen, Martin

##### **PhD students, graduates and post doctoral researchers**

Hansen, Lars Henrik

##### **Technical staff**

Hagensen, Flemming

Lange, Rolf

Larsen, Gert

##### **Secretaries**

Andersen, Mette Kuhlmann (till 31 July)

Hansen, Anne Marie

Henriksen, Mette Porsdal (on leave till 12 March)

Westermann, Kirsten



**Programme: Aerodynamic Design****Scientific staff**

Fuglsang, Peter

Larsen, Gunner

Larsen, Torben Juul (from 15 August)

Madsen, Helge Aagaard

Petersen, Jørgen Thirstrup

*Flemming Rasmussen, Programme Head*

Sørensen, Niels Nørmark

Thomsen, Kenneth

Vølund, Per (till 30 September)

**PhD students, graduates and post doctoral researchers**

Bak, Christian

Baumgart, Andreas (from 1 June)

Bertagnolio, Franck

Dahl, Kristian Skriver

Johansen, Jeppe (on leave from 1 September)

**Secretary**

Westermann, Kirsten

**Programme: Electric Design and Control****Scientific staff:**

Bindner, Henrik W.

*Hjuler Jensen, Peter, Programme Head*

Søndergaard, Lars (till 31 March)

Sørensen, Poul

**PhD students, graduates and post doctoral researchers**

Hansen, Anka Daniela (from 15 January)

**Secretary**

Madsen, Jytte

**Programme: Wind Power Meteorology****Scientific staff**

Frank, Helmut

Højstrup, Jørgen (on leave till 31 May 2001)

Kristensen, Leif

*Landberg, Lars, Programme Head*

Mann, Jakob

Mortensen, Niels Gylling

Rathmann, Ole

**PhD students, graduates and post doctoral researchers**

Bergmann, Juan

Giebel, Gregor

Joensen, Alfred

Larsen, Lisbeth (till 31 July)

Lange, Bernhard (from 1 July)

Sempreviva, Anna Maria

**PhD theses**

Sempreviva Anna Maria

**Secretary**

Nielsen, Rikke (from 1 August)

**Programme: Wind Energy and Atmospheric Processes****Scientific staff**

Astrup, Poul

Gryning, Sven Erik

Hummelshøj, Poul

Jensen, Niels Otto

Jørgensen, Hans

*Larsen, Søren, Programme Head*

Mikkelsen, Torben

Nielsen, Morten

Thykier-Nielsen, Søren

**PhD students, graduates and post doctoral researchers**

Dellwik, Ebba (from 7 September)

Falk, Anne Katrine Vinther

Geernaert, Lise Lotte Sørensen

Hasager, Charlotte Bay

Helin, Astrid (till 31 August)

Kjeld, Jørgen Friis

Moltesen, Asta (from 15 September)

Vignati, Elisabetta

**PhD theses**

Nielsen, Morten

**Secretary**

Skrumsager, Birthe

**Special Task: Tests and Measurements****Scientific staff**

Antoniou, Ioannis

Fischer-Nielsen, Thomas (till 31 July)

Grove-Nielsen, Erik (Sparkær)

Krogsgaard, Jørgen

Lind, Søren Ømann

Paulsen, Uwe Schmidt

*Pedersen, Troels Friis, Programme Head*

Petersen, Søren Markkilde

**Technical staff**

Christensen, Kurt

Hansen, Per (from 15 January)

Hansen, Stener

Høst, Oluf

Lund-Thomsen, Hans (Sparkær)

Nielsen, Finn Linke

Rasmussen, Michael

**Secretary**

Hansen, Anne-Marie

**Special Task: Type Approval****Scientific staff**

Kock, Carsten Weber (till 30 November)

Schaarup, Jesper (from 1 February)

*Skamris, Carsten, Head*

## **Special Task: Experimental Meteorology**

### **Scientific staff**

Courtney, Mike

*Larsen, Søren, Head*

Sanderhoff, Peter

### **Technical staff**

Christensen, Lars

Hansen, Arent

Hansen, Finn

Hansen, John

Jensen, Gunnar

Lund, Søren

Nielsen, Jan

### **Secretary**

Skrumsager, Birthe

## **7.2 Guest Scientists**

Barthelmie, Rebecca	08.06 - 09.09	Univ. of Indiana, USA
Batchvarova, Ekaterina	12.05 - 13.06	Nat. Inst. of Met. & Hydrology,
	19.10 - 29.11	Sofia, Bulgaria
Deme, Sandor	01.02 - 21.02	KFKI, Budapest, Hungary
Goodwill, Gilbert	30.05 - 14.06	Kamada Science & Design
		Monterey, CA, USA
Golitsyn, George	13.07 - 12.08	Academy of Sciences
		Moscow, Russia
Grachev, Andrey	08.06 - 05.07	Academy of Sciences, Moscow,
		Russia
Gultureanu Beatrice	27.04 - 20.07	Univ. of Ploiesti, Romania
Gultureanu, Dan	27.04 - 20.07	Univ. of Ploiesti, Romania
Heathfield, Duncan	05.01 - 16.01	University of Edinburgh (UK)
	23.03 - 30.03	
	09.11 - 13.11	
Hongisto, Marke	18.11 - 19.11	FMI, Helsinki, Finland
Jones, Ian	20.09 - 10.11	Univ. of Sydney, Australia
Kunz, Gerard		TNO, The Netherlands
Lima-E-Silva, Pedro	19.01 - 14.02	CNEN, Brazil
Ulke, Graciella	01.05 - 15.05	Univ. of Buenos Aires, Argentina
Wilson, David	01.06 - 30.09	Univ. of Albana, Edm., Canada
Yaglom, A.M.	06.07 - 18.07	Mass. Inst. of Technol., USA
Zecchetto, S.	09.11 - 10.11	Venezia, Italy
Zilitinkevich, S.	01.01 - 31.03	Max-Planck-Inst., Hamburg (DE)

### 7.3 Short-term visitors (one week or less)

Coppin, Peter	26.10 - 30.10	CSIRO, Canberra, Australia
Dellwik, Ebba	15.03	Chalmers, Gothenburg, Sweden
Evans, Jenni	10.06 - 12.06	Penn State University, USA
Kouchi, Akinori	05.10 - 06.10	Nagasaki Res. & Dev. Centre, Japan
Leeuw, Gerrit de	20.04 - 21.04	TNO, the Netherlands
Moreno, Jose	14.03 - 20.03	Barcelona, Spain
	28.04 - 29.04	
Sorbjan, Zbigniev	08.06 - 13.06	Univ. of Oklahoma, USA
Starkov, Alexander	14.06 - 20.06	RDIEE, Istra, Moscow, Russia
	15.12 - 19.12	
Tillman, Jim	02.11 - 08.11	University of Washington,
	25.11 - 28.11	Seattle, WA, USA
Tsinober, Arkady	13.09 - 19.09	Tel Aviv University, Israel
Watson, Rich	05.01 - 09.01	Univ. College, Dublin (IE)
Zilitinkevich, Sergej	23.05 - 29.05	Uppsala University, Sweden

Title and authors

Wind Energy and Atmospheric Physics Department Annual Report 1998

Peter Hauge Madsen, Per Nørgård and Birthe Skrumsager (eds)

ISBN		ISSN	
87-550-2516-1		0106-2840	
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Department or group		Date	
Wind Energy and Atmospheric Physics		November 1999	
Groups own reg. number(s)		Project/contract No(s)	
Pages	Tables	Illustrations	References
67		14	

Abstract (max. 2000 characters) The report describes the work of the Wind Energy and Atmospheric Physics Department at Risø National Laboratory in 1998. The research of the department aims to develop new opportunities in the exploitation of wind energy and to map and alleviate atmospheric aspects of environmental problems. The expertise of the department is utilised in commercial activities such as wind turbine testing and certification, training programmes, courses and consultancy services to industry, authorities and Danish and international organisations on wind energy and atmospheric environmental impact. A summary of the department's activities in 1998 is presented, including lists of publications, lectures, committees and staff members.

Descriptors INIS/EDB

AIR POLLUTION; BOUNDARY LAYERS; METEOROLOGY; PROGRESS REPORT; RESEARCH PROGRAMS; RISØE NATIONAL LABORATORY; WIND TURBINES

Available on request from Information Service Department, Risoe National Laboratory,  
(Information Service Department, Risoe National Laboratory), P.O. Box 49, DK-4000 Roskilde, Denmark.  
Telephone +45 46 77 46 77, ext. 4004/4005, Telefax +45 46 77 40 13

## Objective:

The purpose of the department is - by research and development and by providing technical services in areas where the department has a special research-based expertise - to establish:

- the scientific background and technological opportunities for the global exploitation of wind energy, the international competitiveness of the wind energy industry and the implementation of the Danish energy policies, and
- the atmospheric physics basis for the assessment and prediction of wind effects, transport, transformation and exchange of air pollution and other airborne sub-stances as well as for the consequences in case of emergencies

## Organisation:

The department management consists of:

- *Erik Lundtang Petersen*, Head (ext.. 5001)
- *Peter Hauge Madsen*, Deputy head (ext. 5011)

The research is organised in the research programs:

- Atmospheric Transport & Exchange  
*Søren Larsen*, Head (ext. 5012)
- Wind Power Meteorology  
*Lars Landberg*, Head (ext. 5024)
- Aero-elastic Design  
*Flemming Rasmussen*, Head (ext. 5048)
- Electric Design & Control  
*Peter Hjuler Jensen*, Head (ext. 5037)
- Wind Turbines  
*Peter Hjuler Jensen*, Head (ext. 5037)

The special services are:

- Wind Turbine & Blade Testing  
*Troels Friis Petersen*, Head (ext. 5042)
- Type-Approvals & Certification  
*Carsten Skamris*, Head (ext. 5066)
- Experimental Meteorology  
*Søren Larsen*, Head (ext. 5012)

## Publications:

International Publications	60
Danish Publications:	39
Conference Papers with Proc.	68
Popular Scientific Publications	6
Unpublished Lectures	92

## Staff :

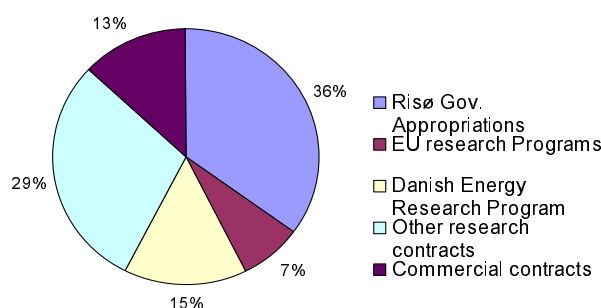
Academic staff:	59
Technical/administrative staff:	25
Ph.D. and Post Docs	9

## Finances:

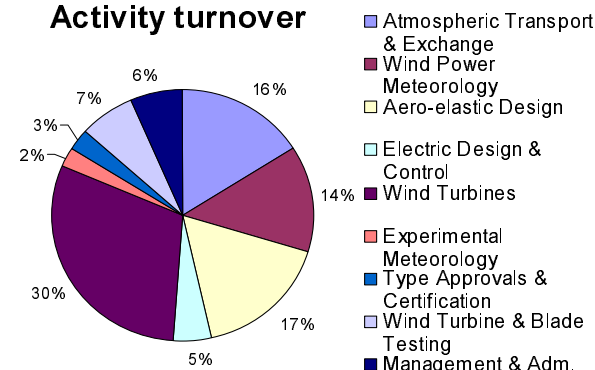
Turnover: DKK 77.3 million

Research contracts: DKK 50.3 million

## Funding Sources 1998



## Activity turnover



## Expenses

